Technological systems across contexts: Designing and exploring learning possibilities in Swedish compulsory technology education

Åke Ingerman, University of Gothenburg
Maria Svensson, University of Gothenburg
Anders Berglund, Uppsala University
Shirley Booth, University of Gothenburg
Jonas Emanuelsson, University of Gothenburg

Abstract

In the world we live in there are powerful broad frameworks for understanding specific objects, relationships and events. This paper focuses the learning and understanding of one such framework, namely, technological systems, which are complex systems of technical and human components that facilitate much of the experienced needs of modern society. Technological systems are constituted of transformation and transport, acting on matter, energy and information. This paper outlines a larger project, which is expected to contribute substantially to a pedagogical knowledge base for systems thinking in technology. The specific focus of the paper will be the first step in the project – the development of a design for learning technological systems in Swedish compulsory school based on previous empirical studies as well as theoretical principles. The core of that design revolves around creating patterns of variation supporting the separation and differentiation in and between four empirically identified dimensions of variation: resource, intention, internal structure and external structure. It also includes patterns of variation that support the fusion of these dimensions and simultaneous awareness of several different technological systems, focusing their systemic nature.

Introduction

In contemporary society technological systems encompass much of what characterises technology: Technological systems are goal-directed, delivering both to society and to individuals, but have also unwanted effects. Many such effects concern detrimental influence on the environment, and in understanding the grounds for sustainable development, understanding the systemic aspects of technology (and nature) are paramount. At the same time, technological systems are not tangible, and as such is a theme less supported by informal learning than other themes in technology.

The topic of ‘technological systems’ form an important part of the school subject Technology in Swedish schools, where it embraces a broad definition of technology related to human endeavours. The syllabus for the Swedish national curriculum in technology in the lower secondary school includes such items as “How components and subsystems work together in larger systems, such as the production and distribution of electricity... The Internet and other global technical systems. ... Systems – their advantages, risks and vulnerabilities.”

Empirical studies so far suggest that the basic capability in (complex) systems thinking is the recognition of a meaningful framework of relationships connecting seemingly isolated events and components to become an interconnected whole, also operating on a different level (Assaraf, Dodick & Tripto 2011; Jacobsen & Wilensky 2006) – i.e. seeing something *as* a system (c.f. recognising a phenomenon, as described in Marton & Booth 1997). This is difficult since many aspects of systems are never directly experienced (Hmelo-Silver & Azevedo 2006). Some tentative characteristics of thinking and reasoning in relation to complex systems are to

- recognise multi-causality and emergence – that several different events on one level may give rise to a qualitatively different pattern of events on another level (Jacobsen & Wilensky 2006).
- identify cycles of matter, energy and information (de Weck, Roos & Magee 2011; Eliam 2012; Svensson 2011b; Svensson & Ingerman 2010)
- recognise the nature of temporality, directionality and (dynamic) equilibrium (Jacobsen & Wilensky 2006) and
- consider consequences of and on human interaction with the world (de Weck, Roos & Magee 2011; Mohan, Chen & Anderson 2009).

Recent work concerning technological systems as an educational topic, highlighting descriptions in textbooks and national guidelines as well as teachers' efforts to include this theme also form an important background for the project (Klasander 2010).

In the project outlined here, the aim is to explore teaching and learning of technological systems for pupils in school years 7 – 9, and the relationships and mutual interdependencies between individual learning and collective learning comes into focus. In collaboration with the teachers we will design lessons that vary over different technological systems as well as aspects of them.

The central research question is:

What does it take to learn, and what does it mean to teach for learning, Technological Systems, their constituent parts and the relations between them when the systems are embedded in different contexts and encountered in different pedagogical structures?

From the overriding research question emerge three sub-questions:

- What do students in the lower secondary school understand of technological systems in terms of their constituent parts when given opportunities to explore systems in different contexts?

- What can teachers offer as a platform for developing a general understanding of technological systems with recourse to different systems set in different contexts?

- How are technological systems expressed in different contexts in different pedagogical structures in the classroom arena?

Empirical design

Data will be taken from the lower secondary school, years 7-9, wherever examples of technological systems are being taught.

The empirical data generation will include four steps.

1. Establishing a team of 8-10 teachers and the researchers from the project with common grounds on the knowledge theme and common basic ideas for a pedagogical approach. That will include a "course" for teachers on technological systems, following Klasander (2010).

2. Develop in the team a shared plan for teaching over a series of lessons (cf. Vikström 2005), that converges what is understood as intended outcomes, and what may be productive learning activities in terms of establishing overall patterns of variation, as drawn from the work of Svensson (2011a) and Klasander (2010). This plan will explicitly make use of variation in context as a way of exploring the abstract technological system, expanding the understanding and ways of expressing these understandings in classroom interactions – in verbal, written and representational forms. It will also cut across different pedagogical structures – teacher centred, group discussions, practical activity, and assessment activity.

3. Audio and video recording in classrooms with focus on whole class teaching or group discussion and activity as appropriate. We anticipate recordings from 3-5 lessons per classroom. Copies will be made of students' written material, textbook pages, and worksheets used in class.

4. Data collection to inform the research questions as a whole: Relevant parts of the teachers' planning, assessment, and documentation, which may include written documents, as well as recordings of conversations with and between teachers will be collected throughout the planning and implementation.

Analytical design

The project will be framed, both theoretically and analytically, by the qualitative research approach of phenomenography and variation theory of learning. This approach is capable of supporting the investigation of the process of learning in naturalistic settings close to educational practice in a way that reflects that it is a process of learning specifically about technology and technological systems.

Phenomenographic studies aim to reveal qualitative variation in the ways people understand specific phenomena (Marton & Booth 1997) – for example, the force concept or technological systems (Svensson, Zetterqvist & Ingerman 2012) – and the critical differences that distinguish one way of understanding from another. Variation theory (Ingerman, Linder & Marshall 2009; Marton & Booth 1997), as well as the associated action research approach, learning study (Marton & Pang 2006), offers a theoretically and empirically grounded path to systematically fostering the affordance of understanding a phenomenon – an object of learning – as constituted in pedagogical and classroom practice. The core of the variation theory of learning concerns what is critical for learning, and what essential variation around critical aspects is offered to the students in a pedagogical situation. Teaching design based on such identified essential variation results in remarkable and reproducible gains in learning outcomes in the teaching of various subjects (Marton & Pang 2006).

The project will investigate and relate two levels of the process of learning: one is an aggregated level and one is a moment-to-moment level. Here, *aggregated* refers to the results that describe the overall recurrent structures of understanding and communicative acts, which is taken to include acts that rearrange some aspect of the physical world, and, such results are the outcome of a phenomenographic study. In addition to offering guidance on the organisation of learning activities, variation theory has much to offer in analysing communication for knowledge performances as a *moment-to-moment* production of learning (Ingerman, Linder & Marshall 2009). A micro-analysis approach entails analysing the constitution of variation of critical aspects of systems – potentially embedded in the task at hand and pedagogically activated by the students and teachers. This encompasses classifying the kind of possibilities the students develop in terms of variation, or patterns of variation, in critical aspects, and looking at how the students develop their understanding of the situation, as manifest in their communication with each other and the world.

A tentative design for learning technological systems

In this paper, we focus on the first step of the full project – the design of teaching of technological systems, to be based on previous empirical research, theoretical considerations and identified good practice. Below we describe a tentative design, to be further revised in collaboration with teachers.

The design is based, with respect to previous research, on results emanating from three research perspectives: 1) variation theory design principles, 2) empirical descriptions of key challenges in understanding complex systems, and 3) empirical descriptions of aspects that are critical for learning technological systems in the targeted educational level. The base of identified good practice is on the one hand general and based on research about pedagogical conditions that are favourable for learning, e.g. a student centred and learning focused approach. On the other hand, more specifically, lacking solid empirical results in the area of technological systems, the design is based on good practice in technology education in lower secondary school as identified by the teachers and researchers involved in the project. Such identified good practice may be refined and developed during the project through the collaborative work as well as through the analysis of practice inherent in the project.

The basics of variation theory design is the explicit use of focusing variation across what can be identified as critical aspects of what is to be understood. Such critical aspects can be identified through empirical investigation of ways of understanding, in this case, technological systems. Based on such empirical investigations (Svensson 2011a;b; Svensson & Ingerman 2010; Svensson, Zetterqvist & Ingerman 2012) we identify four dimensions of variation:

- Resource – What the system acts on, in terms of matter, energy and information.
- Intention – What can be identified as the system's intended function (c.f. the intended function of artefacts, de Vries 2005).
- Internal structure – How the systems is organised in terms of components, framework of relationships and human agency.
- External structure – How the system is organised in terms of how it interacts with the surrounding world, such as other technological, natural and social systems.

We emphasize that a dimension of variation is constituted of the ways in which people understand that phenomenon and is not inherent in the phenomenon as such. In each of the dimensions of variation, ways of understanding that dimension of the system can be seen as either referring to systems characteristics or non-systems characteristics. It is essential that patterns of variation in the classroom support the pupils in experiencing such qualitative differences in each dimension through recognising examples that are systemic and differentiating them from examples that are not – this is in variation theory termed as a pattern of separation through contrast. Further, the scope of the pedagogical design must be able to afford a fusion of these dimensions into a whole –seeing different aspects of technological systems as aspects of the same phenomenon, that is, technological systems in general. This is in variation theory termed as a pattern of fusion (patterns of variation are further explained in Marton, Runesson & Tsui 2004).

Through analysing the four dimensions of variation, patterns of separation through contrast can be identified as below. In the dimension of resource, there is a qualitative difference between discussing a *specific* resource, such as the electric current in a desk lamp, and a *systems* resource, such as the energy distribution in the village. A specific design will preferably exemplify resources of different distinct character – only matter, energy or information – where the resource is tightly connected to the idea and delimitation of the system. In practice, working with a mobile phone communication system, an electricity provision system and a goods transport system will provide opportunities to differentiate between resources, as well as between a systems resource and a specific resource.

In the dimension of intention the qualitative shift occurs between on the one hand, a specific person seeing a need and ascribing a technological artefact and its intended function as a way of addressing that need, and on the other hand, when a need becomes recurrent, and a community is established as committed to sustaining a shared intention. For example, contrasting a situation when it is possible for everyone to take their bowl to get drinking water from the river, with when the water that is taken from the river is distributed by communal means, whether piped or bottled, is one way of affording relevant variation in the classroom.

In the dimension of internal structure, the difference lies between seeing components of a system as being organised in a linear format and seeing them as being organised in a network (framework of relationships). This implies differentiating between components and their relationships, where the first transform the system resources, and the second transport them, and seeing both transformation and transportation in relation to the system intention. For example, the distribution of mail includes a series of transformations of the incoming set of mail each day, such as pooling mail from different mailboxes, sorting mail to different destinations, as well as transport between the different points of transformation. Controlling disturbances in the system, such as unclear addresses, weather conditions, strikes and illness, and non-adherence to payment regulations, contribute to the non-linear nature of the system. Creating a pattern of variation highlighting the important differentiations in this dimension of variation is complex. For example, one starting point may be to contrast the structure of messenger-direct-delivered mail with a postal service.

The dimension of external structure is not critical in the same way for the basic capability of recognising a series of events as being organised in a system. Nevertheless, recognising the limits of a system and what surrounds and interacts with it is important for the differentiation between the particular system considered, and other possible systems that could have been considered, add to the critical differences aligned with the other three dimensions.

Following such patterns of separation, variation that cuts across the individual dimensions is necessary, to afford a fusion of their meaning into an interconnected whole. There are probably several levels in understanding both specific and general technological systems; a start for fusion may be pedagogical tasks focusing the same technological system and comparing different historical and national installations of the system, for example, food provision systems. A further step necessitates the simultaneous discussion of several fully-fledged technological systems differing in the dimensions as described above.

In our design we have identified three major pedagogical contexts in which the four dimensions of variation will be present for pedagogical and research purposes:

- Analysing problems, such as considering how the systemic nature of a particular system changes when a central component or aspect of the framework of relationships changes. Examples are the break of power wires connecting northern and southern Sweden and the merging of the mobile and land-line phone communication systems that is underway.

- Working with representations. Examples are the tram time-tables in conjunction with the map of destinations, or a flow chart of normal mail distribution, and diagrams of power usage across different times of the year and times of day.

- Experiencing systems, coming into experiential rather than conceptual contact with systems. Examples involve visiting central components in different systems, such as airports, sewage works, or inspecting a power generator.

Conclusion

We have now outlined the overall aims, intentions and theoretical considerations of the research project as a whole, and given more detail of the first phase in which the research team and the teachers involved will establish a framework for designing lessons on technological systems. The design principles are now well founded and need to be put into practice through intensive dialogues with the teachers who will be working in the classrooms, with respect not only to the pedagogical and system theories involved but also with respect to productive examples for the different pedagogical interventions. The extent to which a common ground is established is an empirical question that we will be addressing continuously as the project evolves, along with the research questions on which the project is founded. The extent to which the chosen pedagogical situations for research are productive for underpinning understanding of technological systems will be a major result of the project.

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