Teaching and learning system thinking in technology

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Abstract

Complex technological systems have emerged during the last decade as an important strand in technology teaching in several national curricula for compulsory school. However, even though understanding the systemic aspects and connected nature of contemporary society, it remains unclear what such understanding entails in detail, and even more unclear what may constitute good teaching. We present the results from a teaching-learning design project on the topic of large societal and complex technological systems, which are seen as constituted of transformation and transport, acting on matter, energy and information.

The main results are a suggested and evaluated plan of teaching developed in collaboration with a team of technology teachers, as well as descriptions of how pupils' system thinking is constituted in terms of four basic aspects: Resource and intention of the system; System component constitution; Process and transformation in components and system; Network character. In total, a teaching plan spanning four lessons was realised in four different classrooms, with classes' sizes ranging 15 to 25 pupils in the ages 14 and 15. The teaching design progresses through focusing specific parts of various systems, for example the transformation of polluted water to clean water in a water purification plant as part of the water supply system. There is an emphasis on the function of the part in relation to the system on the one hand, and on how the part is and can be realised technically, taking care to relate the latter to what is taken up in other curricular strands of technology. The last part focuses the examination of technological systems as constituted by interacting and meaningful parts, where their network nature may emerge.

Keywords

Complex technological systems, phenomenography and variation theory, system thinking, teaching and learning technology

Introduction

Complex technological systems, such as the water supply system, internet or the railway transportation system, have emerged during the last decade as an important strand in technology teaching in several national curricula for compulsory school. However, even though understanding the systemic aspects and connected nature of contemporary society, it remains unclear what such understanding entails in detail, and even more unclear what may constitute good teaching. This study attempts to contribute towards alleviating this through collaborative research with technology teachers, both generating possibilities for teaching and explicating what constitutes understanding in the context of complex technological systems.

Research questions

- What may constitute basic aspects of understanding complex technological systems from the perspective of learners?
- What are productive ways of teaching that may facilitate discerning and understanding such basic aspects of complex technological systems?

Literature

This research project concerns teaching and learning of technological systems, which are complex systems of technical and human components that facilitate much of the experienced needs of modern society, such as internet (information), water supply system (matter) and the power grid (energy). Systems that are not tangible and consist of components and connections on different levels as well as human interaction could be described as complex technological systems. In the literature, there have been several attempts to explicate what technological systems are and what may be valuable to know about them (cf. Dusek, 2007; Hughes, 1987). However, there has been little research that investigates what pupils may understand about such systems, or how teaching may be organised. Nevertheless, there is some research recently carried out that concluded that pupils in the later years of compulsory school understand the structure of systems better than they understand the intention and interaction of technological systems (Koski & de Vries, 2013; Svensson, 2011; Örtnäs, 2007), and that teachers lack knowledge about system thinking and are unfamiliar with how to teach about complex technological systems (Klasander, 2010; Svensson & Klasander, 2012).

Understanding technological systems imply system thinking. 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 (cf. 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).

Theoretical underpinnings

The study is theoretically, analytically, as well as methodically, in line with the phenomenography and variation theory tradition (see, for example, Marton & Booth, 1997 and Marton & Tsui, 2004). Learning is understood as the learning of something, and that there are some aspects that are more critical for learning than other aspects. While learning is understood as individual, one important consideration in this project is the collective nature of expressions of knowledge in classroom situations, in whole class as well as in small group discussions (cf. Ingerman, 2013).

Research design

We present the results from a Swedish design research project, where six technology teachers in compulsory school collaborated with the research team. The collaborative phase – which concerned design, realisation and reflection regarding teaching of technological system – resembles an action research approach, geared towards generating design, and thus part of the broader design research movement (The Design-Based Research Collective, 2003) and more specifically similar in many respects to a learning study (Marton & Pang, 2006). However, the analytical phase of the project address questions that falls outside the scope of most action and design research, and concerns fundamental queries on learning processes and the constitution of technological systems as a knowledge area.

The starting point for the project was previous research on teaching and learning technological system (Klasander, 2010; Svensson & Ingerman, 2010; Svensson, 2011), in particular Svensson's phenomenographic study of pupils' experiences of technological systems and their implications for teaching in terms of three key dimensions: resource, intention, structure. The collaborative work started with four seminars in which technological systems as knowledge area was discussed with the ambition of forming a shared understanding in the group. Then followed two rounds of teaching design and reflection. The process was carefully documented through audio and video recordings as well as notes and collection of written material. Throughout the process elements of analysis were interspersed, and can be seen to have a dialogical relationship to the reflection in the teacher-researcher meetings. Thus, there is a gradual shift from action research owned jointly by teachers and researchers towards the analytical process, carried out by the researchers, at the latter part of the project.

The teaching and the setting

Technology is a separate subject in the Swedish curriculum with specific knowledge requirements for year 6 and year 9. Technological system as part of the subject is poorly established and the content is not described in detail in the curriculum (Skolverket, 2011). Klasander & Svensson (2012) point out that individual teachers lack the knowledge and experience to teach about systems. The teachers that became involved in the project, was the result of a positive selection process, where they volunteered, and all of them showed an engagement as technology teachers and were formally qualified as technology teachers.

The initial seminars considered aspects such as connections to the technology domain context (transformation, transportation, control, regulation and storage) and concrete ways of making comparison across different systems.

The teaching plan consisted of four lessons focusing technological systems. The first lesson took its starting point from the pupils' daily morning habits – the pupils were put in groups without a theme introduction with the assignment to document their morning habits, and sort habits into common groups. They were then asked to consider what was needed in order to facilitate these different groups of habits. The second and third lesson focused constructing physical or representational models of systems, in some cases of different systems and in some cases of different components within a system. One part of the fourth lesson consisted of group presentations of their models, and comparisons and relationships between the models. Another part of this lesson (or in some cases a fifth lesson) focused group discussions on what would be the consequences of disaster or major malfunction in one or several systems in society.

The teaching design was realised in four different classrooms by four different teachers, as normal lessons in the subject technology. Their classrooms consisted of 15-25 pupils in each. The design allowed for variation in realisation, and the teachers accordingly adapted it to the local school tradition and their personal way of teaching. One class was in their final year in compulsory school (15 years old) and the others were in the second last year.

Data collection

Classroom teaching was documented through audio and video recording with high technical quality. Several video and audio recordings were made in each classroom. One camera focused the teacher, and two others focused small groups of pupils, both when they interacted in the whole class setting and had separate discussions or practical work. Complementing interviews were made with a small set of pupils. The teachers were asked to reflect immediately after the lesson. All interviews were recorded, as well as seminar discussions with teachers and researchers, and all data stored securely.

Analysis

Throughout the analysis, we used the video material as a whole, since it was important to keep the quality of an overall understanding of the teaching. It was also important to identify key events and the type of knowledge about technical systems that was expressed, both in teaching and in pupils' conversations. No overall transcriptions were made, but selected sections of the material have been transcribed as the analysis progressed.

In relation to the first research question, we primarily focused on one specific part of the material, when pupils presented models of different systems. In total about 25 groups with pupils presented. Through comparing what was said about systems by different groups in their presentation, and drawing on aspects identified in previous studies; resource (matter, energy and information), intention (the aim with system for individuals and society), structure (components and connections between components and other systems), we identified four basic aspects that in different ways connect to system thinking. These aspects were descriptive of the whole material in the sense that the extent to which they were dealt with in the presentation constituted the variation in quality of the presentations.

In relation to the second research question, we made use of the basic aspects identified in the first analysis to characterise the realisation in the four different classrooms. Part of this was done iteratively and included revision of the teaching design. In the next step we identified indications of productive ways of teaching across the variation between classrooms in relation to different expressions of systems thinking. Thus, we can suggest how different aspects of the teaching connect to and are reflected in the qualities in the presentations.

Results

Insights on understanding of technological systems

The results show a range of how pupils in creating models/representations and in descriptions may articulate their knowledge of system aspects, appropriate for the level and scope of teaching. On an overall level, we identify four basic aspects of system thinking along which independent qualities in different student expressions align. They connect to and constitute both (physical and principle) organisation and (technical) function of the specific system discussed. In abstracted form, they are:

A. Resource and intention of system, and delimitation of system in relation to intention.
B. System constitution in terms of components (structure)
C. Intra function of components and inter component function in system (process and transformation)
D. Network character

In this context of this paper, we will point to three examples (out of the 25 group presentations) of how such expressions take concrete form. They all have clear qualities of student reasoning about technological systems, expressing one or several of the basic aspects identified. The empirical material as a whole indicates that the different aspects not necessarily may be easily simultaneously expressed – no examples include all aspects at the same time, and it is not clear that one example may be categorised as 'better' than another. However, in some examples, several aspects are simultaneously present at the same time, which we see as valuable. We will detail one such example for illustrative purposes.

The first example concerns a presentation of a water system, focusing distribution of water to households using water towers etc. This example has a typical quality in that the system structure constitution is very clear and delimited in the pupils' expression, and is put in relation to the overall intention of the system (aspect A & B). The expression could develop in quality, for example, through opening the system towards the surroundings and connected systems and/or through adding technical detail of the components.

The second example concerns a presentation of systems connecting to a public transport bus, for example, to electricity, education, wages, planning, traffic rules, petrol, building roads. This example has a quite unusual quality in that the network structure of systems becomes explicit (aspect D). The expression could develop in quality, for example, through making clear the delimitations of the system considered and/or through adding technical detail of the components.

The third example concerns a presentation of a water system, focusing the distribution of water *within* a house, towards the background of the water supply system in society. This example has a strong quality in relation to the technology knowledge domain in that it explicates the process of the water flow in the house and, in particular, the transformation of water (such as from cold to warm, from clean to dirty). They also connect this process to regulation and control in relation to the purpose of water availability at the turn of a water tap, the specific function for the individual user of the system. (basic aspect C against the background of A & B, now including a level of specificity in relation to the individual component of the house and the technical constitution of this component). The expression could develop in quality, for example, through extending the linearly structured process in relation to network dependencies.

The technical quality of the latter example is quite distinctly visible, for example, in the following quote:

> *Boy A - There is an electrical box for the house and a heating boiler, the water is coming here into the heating boiler where the cold water is heated up and then there is also cold water coming out … so the blue line (pointing at a blue string on the model) is cold water and the orange one (pointing at a orange string on the model) is warm water and that one is the main power cable*.

Teaching for learning system thinking in technology

Based on the above descriptions of basic aspects of systems thinking we have identified productive elements of teaching for learning system thinking in technology.
One of the core parts of the design was the open introductory part, where experiences the pupils had in their daily lives – their morning habits – were used to suggest patterns of connections to technological systems. This part of the design seems to be fruitful in supporting the discernment of systems. This was clear both from the general level of system thinking in the presentations of models (almost all pupils displayed clear understanding of some system aspects), but also from the emerging awareness apparent in group discussions about morning habits.

Another part of the design was realised differently in different classrooms. Even though the pupils' construction of a model (in lessons two and three) was common in all the classrooms, the focus and emphasis of the models differed. In one classroom, the pupils constructed models of different 'whole' systems, such as the water supply system, the electricity system or the transportation system. In another classroom, the pupils constructed models of different components of the water supply system or the Swedish electricity system, together constituting the whole system. From the range of presentations it is clear that working with different 'whole' systems gave a low level of technical content. Working with components in some cases gave the results that technical details overshadowed the systemic perspective, while in other cases technical detail and framing was put in relationship to systemic thinking. Looking at the teaching in retrospect, similar patterns can be seen in how the teacher addresses this balance. Our conclusion is that it is important that both the design of the task and how the teacher addresses the content reflects a balance between technical details and the systemic perspective in order for facilitating systemic thinking connected to the technological knowledge domain.

In connection to the classroom where there was a balance, there also emerged a possibility to discuss the system in terms of process, taking into account technical details of how components interacted to propel the system towards fulfilling the overall function of the system. This quality was observed both in the teaching and in some of the group presentations.

Discussion/Conclusion

The results from the study demonstrate that pupils in compulsory school can develop a basic grasp of technological systems without much prior teaching. At the same time, system thinking appear to be challenging both for teachers and pupils. Teachers and pupils here grapple with dealing simultaneously with the network character and the detail of component-system function.

The teaching in this study included establishing notions relevant for discussing systems, such as components, system control, input, process and output. Such notions could be established in relation to 'simple' technical systems, such as the bicycle, computer or the engine, and be taught before addressing complex technological systems (cf. Koski & de Vries, 2013). On the one hand, this would support progression with respect to system thinking in technology, and on the other hand, this would allow focusing complexity and the network character in the kinds of system discussed here.

There are questions that the study indicates would be valuable to address in further research. For example, the results point a possible tension between developing system thinking on the general level, or progressing through extensive interaction with and learning about particular systems. This is reciprocal with whether learning about systems in general is better than learning about technological systems in particular and similar learning challenges regarding, for example, complex natural systems (cf. Assaraf, Dodick & Tripto, 2011).

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