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Preconceptions about technical systems prevalent amongst upper secondary school pupils

Ümit Köycü and Marc de Vries
Delft University of Technology
The Netherlands

Abstract

In the Netherlands there is an interest in implementing engineering as part of K-12 general education. In order to know what the pupils' perception of the system concept at that level is, research into that was conducted. This study was not only carried out in the Netherlands in six schools across the country, but for comparison also in Turkey in six schools across the country. During the qualitative preparation of the research, the pupils were asked to describe what a technical system is according to them. In the quantitative main part of the study, pupils were asked to respond to 44 True/False statements in which they could indicate what a technical system is. Factor analysis has been performed to reveal the dimensions of the concept of systems that the pupils have in their minds. In contrast to studies among pupils of the lower secondary school, a clear concept about a technical system was found. The differences between male and female respondents with regard to the concept of the system, found in lower secondary education, were also found in upper secondary education. This is in contrast with what was found for the concept of engineering. The predominant knowledge of pupils with regard to the concept of the system indicated a reasonable image of technology, depending on whether it is taught in a school subject.

Keywords

Concepts; technical systems; engineering; upper secondary school

Introduction

In order to create upper secondary education teaching materials suitable for the subject of engineering, the first step is to obtain an insight into the already existing concept and image that pupils have about the essential aspects of the subject. The purpose of this article is to examine the pre-existing view of pupils with regard to engineering systems before implementing this topic in the curriculum of the high school engineering subject. In many countries, e.g., the USA, Sweden and The Netherlands, there is an interest in engineering as part of developing technological literacy. According to Svensson (2011) the teaching of the system-concept emerges as an essential element of engineering education. Technological systems have emerged as an important part of technology education in national curricula for compulsory secondary education. Systems thinking is necessary to understand technological systems and other systems.

Empirical studies so far suggest that the basic skill in (complex) systems thinking is the recognition of a meaningful framework of relationships connecting seemingly isolated events and components to become an interconnected whole, which also operates on another level (Assaraf, et al., 2013; Jacobsen & Wilensky, 2006)—i.e., seeing something as a system. This is difficult because many aspects of systems are never directly experienced (Hmelo-Silver & Azevedo, 2006). Therefore, there is a need for teaching materials that incorporate technical understanding into school curriculums. The necessary skills for citizenship and lifelong learning of the 21st century is, according to the Organization for Economic Co-operation and Development (OECD, 2018), a general set of skills of reading, writing, arithmetic and problem solving in particularly technology-rich environments. In addition, the National Academy of Engineering (NAE) emphasises the importance of engineering education at the pre-university level (Committee on Standards for K-12 Engineering Education, 2010).

Solving problems in these complex situations requires systems thinking: the ability to understand and analyse every part of a system, how it works and interacts with other components, using knowledge from different technical areas (Carlsson & Stankiewicz, 1991).

Systems thinking does not always come naturally, and that is where a school subject with systems engineering comes into play. While many individual engineering disciplines can include systems engineering and systems thinking in a bachelor's or master's degree, this is likely only in the context of how that particular discipline fits into a larger system. In order to gain a good understanding of systems engineering and the skills to apply systems thinking, pursuing a targeted formatting of a secondary school subject is the way to go (Adams et al., 2014). In the Netherlands, there is not yet a substantial movement to introduce engineering in secondary education, but the first initiatives are currently present in the form of education in the field of the subject Onderzoeken en Ontwerpen (“research and design”) in a type of school called Technasium (Prins et al., 2011).

In the past decade, in which several countries introduced engineering education as a successor to technology education, studies of pupils' concepts of engineering systems were found to be incorrect because attainment targets for the subjects in which this was taught were vaguely formulated (Nordstrom & Korpelainen, 2011). Previous studies have shown that the lack of an established method complicates technology teachers’ ability to design and evaluate their formative and summative teaching approaches to accommodate the pupils' specific levels of understanding (Hartell, 2015; De Vries et al., 2007). An increasing need has arisen to create teaching materials in which clear core objectives are set to teach technological literacy in which technical understanding of the system is an indispensable part.

With this in mind, we decided to conduct research into pupils’ understanding of the technical system concept. Upper secondary education seems a good starting point for engineering, as it often requires more knowledge of scientific concepts, principles and mathematics that pupils build in lower secondary education. We have chosen the fourth grade (K10) because at this stage they begin their specialisation with regard to their choice of further study. Additionally, this is the start of their upper secondary education according to the Dutch system of education (Van der Bij et al., 2016). To see if Dutch pupils differ from pupils elsewhere, we decided to include a second country in the study, namely Turkey (mainly for practical reasons—existing contacts—but also because Turkey has little technology education in the curriculum). Little has been done in this area so far, but it is emerging in recent years.

The emergence of technology education concepts was described in a study by Rossouw et al. (2011) that aimed to formulate core concepts for technology education. In this study the concepts of "design (as a verb)", "system", "modeling", "social interaction" and "optimization" received the highest average score from the Delphi experts in technology education. The concept “system” is in education subject of further study, such as in Sweden it has been investigated how pupils experience systems in technology education (Svensson & Klasander, 2012), what teachers perceive about technical systems and the role of this in problem solving and critical thinking (Hallstrom & Klasander 2017). This study aims to clarify the preconceptions that prevail among pupils in K-10. A planned follow-up study will be aimed at identifying the influence of teaching materials on the results of education in the concept of technical systems.

Research methodology

In the preparatory part of this study, we used pupil essays to explore the pupils' concept of engineering systems. A total of 80 essays were used to find key words. In the essay part, respondents had to write their idea of a technical system on a piece of paper. The papers were collected and analysed. No specific cues for the descriptions were given. Responses were analysed individually through the program IBM SPSS Text Analytics. This method has also previously been used in PATT studies. In those studies, pupils were often asked to write short essays. As we wanted to do a limited international study, we decided to use a method that allows pupils to express their ideas in an equal way. This was done by obtaining essays from two countries, with the assignments given in the pupils' native language. Concerns about the use of this tool in the countries based on their wording and language were addressed by using translations into the primary language of these countries (Dutch and Turkish). Since the 1980s, when PATT studies began, drafting essays has become a popular research method for studying pupils’ ideas about technology and engineering with the added benefit that many teachers also use it in their teaching to help pupils develop understanding of concepts and their relationships (Brown et al., 2010).

To investigate the pupils’ understanding of concept items, we developed a questionnaire, based on the outcomes of the essays. This questionnaire consisted of True/False statements so that pupils had to make a choice whether or not an item asked is a technical system. However, we first decided to conduct an exploratory qualitative study of the image of pupils about technical systems, using essays.

The True/False statements were based on the aforementioned essays to develop those items. The items were formulated as subjects for which pupils had to indicate whether the requested object was an example of a technical system. We had to think carefully about how the questionnaire should be drawn up to avoid researcher influenced results. We tried to tackle the problem of inappropriate interpretation by adding an answer option Other with a comment field.

Since we were interested in examining ideas among pupils, we added some background variables found to be of importance in an earlier study (Köycü & de Vries, 2016). For this study, we selected age, gender, class, the presence of a science journal, science channels on TV, and the presence of a school topic on engineering in their curriculum. The questionnaire, which was completed between September 2015 and January 2016, consisted of 44 items.

The pupils completed the questionnaire in about 10 minutes. Some examples of items are

1. A coffee machine

2. A car
3. A sharpener
4. A pepper mill
5. A steam engine
6. A toothbrush

Where each item was displayed separately, and the respondents could indicate with a True if they thought the item was a technical system or a False if they thought it was not a technical system. There was also an option for Other with a possibility to make a comment if no True/False answer could be given.

The questionnaire was developed in such a way that it could be completed electronically. This facilitated distribution and enabled faster processing as the data was readily available in electronic form immediately. With the help of fellow teachers in participating countries, the questionnaire was administered to 884 pupils with ages ranging from 15 to 17 years old.

Both urban and rural schools were included, in a representative balance for each country. Pupils in two countries wrote essays, which were combined into a total of 80 essays. The item scores and scores on background variables have been processed through SPSS.

Table 1 shows the number of respondents (pupils) per country. Six schools per country were involved. In both countries, the schools were located in very different (urban) parts of the country. This means that the total scores presented here are the result of mixing pupils from very different contexts. Our reason for administering the questionnaire in this way is to get a first impression of possible differences between the two countries. To achieve that goal, we have scattered cities across the country, depending on certain similarities (level of technological development, economy, culture, location). Table 1 lists the cities from which the pupils took part in this survey.

Table 1. Overview of Participants

Country	Cities	Male	Female	Total
The Netherlands	Amsterdam, Rotterdam, Utrecht, Groningen, Oss, Maastricht	214	274	488
Turkey	Istanbul, Ankara, Izmir, Erzurum, Samsun, Gaziantep	211	185	396
	TOTAL	425	459	884

In this article, the focus is on the quantitative analysis of data (the questionnaire). The qualitative part of the research (the essays) was used as the basis for the quantitative instrument (the questionnaire) only.

Results

The following presents the results of the preparatory, qualitative part of the study, using essays to explore the pupils' concept of technical systems. Many of the essays showed a level that was surprisingly higher compared to the results of many previous PATT studies (Bame et al., 1993) which investigated the concept of technology through a questionnaire. We found many keywords in the essays reflected a partial understanding of what technical systems entail. By comparing all the keywords in the essays, we were able to derive four main categories of keywords. Of course, this method of "coding" is never completely separate from existing ideas about technical systems that are being studied. We know from the literature (Hubka & Eder, 2012) that every technical system has a purpose (or a system of purposes consisting of individual purposes and their relationships); it is intended to exert some desired effects on the operands of a transformation process. Every technical system exhibits a behavior which is determined by its mode of action and its structure (a system of elements and their relationships). The intended behaviour is called the system's function. Every technical system accepts inputs (a) from humans, (b) from other technical systems and (c) from the active environment. Some of these inputs are desired, to initiate or control the intended effects, others are secondary inputs acting mainly as disturbances. Each technical system has outputs, which include the desired effects, and the undesired secondary outputs. These desired and secondary outputs influence (a) the operands of the process, (b) humans, (c) other technical systems, and (d) the environment. Every technical system passes through a succession of distinct states, in the course of normal operation, and during its life. Many of these keywords like “process”, “structure”, “function”, “input” and “control” have been found in the essays.

The keyword list is structured by categorising them in relevant dimensions according to the factor analysis described later in this article. The essays give the impression that pupils are only partially aware of different dimensions in technical systems. Some keywords clearly refer to the collaboration dimension in technical systems (examples: interaction, components, collective collaboration). Because of the fact that students wrote in their own language, there were no language errors in the selection of the keywords.

It is also interesting to note that many of the essays contain the strategic choice aspects of technical systems (examples: output, common end goal etc.). Finally, we noted that pupils are also aware of the nature of technical systems where energy often returns (reflected in words such as energy production, manual devices, complex devices, electricity).

We have indication that the teachers have selected high scoring pupils to write the essays, making our sample not representative of all pupils. Comments on this fact were made by teachers participating in the study. However, representativeness to all pupils was not our goal when asking for the essays. We wanted to see what kinds of dimensions were present in the pupils and not what percentage of the pupils these dimensions were present in. With a factor analysis on the quantitative data obtained with the questionnaire, we wanted to find out whether these dimensions were also present in the larger sample of pupils. The resulting categories keyword examples for each category are shown in Table 2.

Table 2: Categories of Concepts in Pupils’ Essays

Complex devices concept	Manual devices concept	Energy producing devices concept	Simple devices concept
A coffee maker	A hand sewing machine	A power plant	A key
A car	A pencil sharpener	A steam engine	A cup
A personal scale	A hand drill	A windmill	A toothbrush
A candy machine	A lighter	A solar cell	A balloon
A refrigerator	A pepper mill		
An exercise bike			
A mobile phone			
A burglary protection			

Below we present the end result of the quantitative part of our research (questionnaire with True/False/Other) after a division into

- a factor analysis that reveals the dimensions in the pupils' concept in relation to technical systems,
- the scale scores derived from this analysis and the differences between sub selections.

A total of 884 usable results of the questionnaire were received from the pupils in the two countries and the different schools where the questionnaire was administered.
Nevertheless, the variations in scores indicate that the scores for many items do not show variations beyond a standard deviation of 0.21. They also indicate that it is useful to look at the general outcomes. An important validity argument is that the items most strongly correlated with a factor allowed a clear and unambiguous interpretation of the factor in all cases. For the pupils' concept of technical systems from the questionnaire, we found the factors from Table 3. The dimensions used as part of the questionnaire were obtained from the factor analysis. The "N of items" column refers to the number of items selected to construct a scale score, based on the factor analysis (items scoring lower on a factor were omitted until a significant drop in Cronbach's Alpha appeared). The Cronbach's Alpha in the second column indicates the reliability of that scale. All scales are deemed reliable if 0.80 is used as the minimum requirement. A gender factor appeared here, just like that found in almost all PATT studies. The scores per scale are shown in Table 4.

Table 3. Concept Factors (Scales) According to Pupils' Concept of Technical Systems

Factor	Cronbach's Alpha	N of items	% of Variance	Cumulative %
Complex devices	0.844	8	19.546	19.546
Manual devices	0.902	5	16.238	35.784
Energy producing devices	0.876	4	15.596	51.380
Simple devices	0.919	4	10.001	61.381

Complex devices, manual devices, energy producing devices and simple devices are the four scales that make up the image scale across technical systems.
For complex devices: 1 represents that complex devices are an important part of the complex devices image, and 2 says it does not constitute a significant part of the image. According to these results, pupils see complexity as an important aspect of technical systems.
For manual devices: 1 indicates that manual use is an important part of technical systems, and 2 means that manual use is not an important part of technical systems. According to these results, pupils do not see manual use as an integral part of technical systems.
For energy generating devices: 1 means that energy generation is an important part of technical systems, and 2 means that energy production does not play an important role in technical systems. These results indicate that energy production usually plays an important role for the pupils.
For simple devices: 1 means that simplicity is an important part of the concept, and 2 means that it is not a significant part. Pupils do not seem to see an important role for simple devices as part of technical systems. This is also in agreement with the first scale, where pupils saw complexity as an important aspect in technical systems.

Table 4. Scores Per Scale According to Pupils' Concept of Technical Systems

N = 884	Complex devices	Manual devices	Energy producing devices	Simple devices
Mean	1.12	1.84	1.22	1.77
Standard deviation	.12	.21	.20	.19

As can be seen in Table 4, there is a small standard deviation for each component. This indicates that there is high level of uniformity in the pupils' perception.

It is interesting which of the background variables has the most significant effect on concepts.

To find out, we performed a regression analysis on the data. In this analysis we have included all background variables asked of pupils. The relationship between the background variables and the scale scores has been demonstrated by performing a regression analysis. The results are shown in Table 5. Significant correlations are in bold and marked "Yes".

Table 5. Regression Analysis of the Relationship Between the Background Variables and the Scale Scores

Dependent → **Independent ↓**	**Complex devices**	**Manual devices**	**Energy producing devices**	**Simple devices**
Country	No	No	No	No
City	No	No	No	No
Gender	**Yes**	No	**Yes**	No
Age	No	No	No	No
Scientific Channel	No	**Yes**	No	No
Scientific Magazine	No	No	No	No
School subject	**Yes**	**Yes**	**Yes**	**Yes**

This regression analysis shows that attending a school subject (teaching aspects of engineering) of the respondents has a significant effect on the perception of pupils in relation to technical systems. Other background variables that have an effect are gender in complex and energy producing devices and scientific channels in manual devices. In this article, we will therefore discuss the background variable "school subject" a bit more. All other variables have a limited effect. In this article we have chosen to describe in more detail only having a school subject that teaches aspects of engineering. Table 6 shows the differences in technical system concepts between genders, whilst Table 7 shows the scale scores per presence of the school subject in the pupils' curriculum.

Table 6. Genders and the Scales According to Pupils' Concept of Technical Systems

	Complex devices	**Manual devices**	**Energy producing devices**	**Simple devices**
Female	1.23	1.81	1.07	1.74
Male	1.01	1.87	1.39	1.80

Table 7. School Subject and the Scales According to Pupils' Concept of Technical Systems

	Complex devices	Manual devices	Energy producing devices	Simple devices
With school subject	1.19	1.72	1.17	1.76
Without school subject	1.05	1.95	1.28	1.79

The numerical difference from the correct answer decreases for pupils with a school subject that teaches engineering aspects. This trend is found in all cases.

Conclusion and discussion

Our study suggests that secondary school pupils in class K-10 have an acceptable but imperfect idea of what technical systems are. Pupils indicated a technical system consists of separate components working together and they mentioned terms like “process”, “input” and “control”. However, they did seem to think that electricity was requisite for a technical system. This is consistent with our previous study on engineering. Our results also suggest a richer concept of technical systems than was found in primary school pupils (Knight & Cunningham, 2004). This is a favourable outcome for the development of technical activities in secondary education, as there already seems to be some foundation on which to expand. The age difference of the respondents compared to the primary pupils explains much of the difference. The results of this study are fairly consistent with previous work in the field.

Previous studies also suggested that elementary and secondary school pupils view the operation on electricity or the presence of a complex nature as a prerequisite for a technical system (Kumari & Saraladevi, 2014). The high school pupils between the ages of 15 and 17 included in our study were, like previous participants, inclined to think that a technical system should not be controlled manually, but certainly electrically. The complex nature of an electrical system should ensure that the user of a technical system only see an end product, or end process but does not need to understand exactly how it works (Sofiani et al., 2017).

These concepts follow the definition given in Collins English Dictionary of a “system” as a group or combination of interrelated, interdependent, or interacting elements forming a collective entity; a methodical or coordinated assemblage of parts, usually forming a self-contained unit. However, there is a clear misconception around electrical functioning of a technical system.

The images of the nature of a technical system that emerged in this study suggest that a technical system must be a complex whole, whereby operation on electricity seems to be a precondition. Almost all of the pupils' essays contained some form of energy production, whether from a power plant or a solar cell on a calculator, and all used electricity.

Manually controlling systems has also been cited as a degradation of a technical system to a tool, which could not be called a technical system anymore. This suggests that in follow-up studies more elements and conditions of technical systems can be questioned after being taught by appropriate lesson materials. In general, in this study, there was not a large demarcation between pupils who believed that engineering systems were complex, could not be controlled manually, used electricity and produced energy. Both the essays and the interview data clearly showed that technical systems were seen as something that uses electricity, involving an energy production or energy conversion that would not be directly visible.

The analysis of the data collected in this study showed similarities between the content of the pupils' essays and their answers to the digital questionnaire. These clearly correspond, even though the questionnaires were collected for a larger number of pupils. It should be noted here that the statistical differences in the values in Table 6 and Table 7 may seem small but are nevertheless significant according to the recession analysis. We realise that this is easier with these large numbers of respondents than with small numbers. We assume that the differences based on gender and the presence of an engineering school subject are worth considering. The results seem to indicate that male pupils seem to have a more correct grasp on technical systems. This is interesting because there were no gender-related differences in earlier research on the concept of engineering. The boys expect more complexity from a technical system, while they better understand that a technical system does not need to produce energy. The mention of green energy may indicate that popular media influenced what the pupils described. There may also be an explanation for the differences. Our considerations here can be expanded by more extensive study. There are several aspects that can be explored in detail.

An interesting question, which should be further explored, is why pupils believe that a technical system should be electrical and not manual. In half of the schools where this study took place, education in aspects of engineering is not part of the curriculum. For those pupils, being electrical was a greater requirement (78% of the essays) than among pupils who have a subject that does teach the aspects of engineering (41% of the essays). Perhaps the use of some tools, such as mobile phones and programmable calculators, in which electricity is often part of the technical system, has influenced what pupils expect of a technical system.

In summary, for education, the conclusion can be drawn that having an engineering school subject helps pupils in the right direction in having a good concept of a technical system, but that specific emphasis should be placed on all aspects to avoid misconceptions. The pupils already have a reasonable idea of what a technical system is but seem to have a more gender-related emphasis on different parts of a technical system. For example, more boys consider complexity to be a condition, while girls believe that a technical system should produce energy. For both groups, a technical system should not be manual. Lesson materials with more emphasis on all parts of a technical system could improve the perception of all pupils on that aspect, reducing the misconceptions of both genders. It could be built on the misconceptions of what pupils seem to have in terms of complexity, manual controllability and energy production in particular.

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