Student Teachers' Mental Models of Everyday Control Systems

The Sensors that Operate the Door

Osnat Dagan

This study aimed to identify student-teachers' mental models of everyday life control systems to develop appropriate instruction processes that help them understand subject matter knowledge (SMK) and pedagogical content knowledge (PCK) (Shulman, 1987) needed for teaching control issues in K-6. The research group consisted of student-teachers from Beit Berl College, Israel studying in preservice programs for kindergarten and primary school teachers. Introduction: Student-teachers study systems and system controls while experimenting with and coding a robot's behavior. Prior to this, student-teachers are asked to explain in text and graphics how the 'automatic door' works. It is important to understand student-teachers' perceptions as in their future career as technology teachers they will have to explain these subjects according to their concepts. Methods: The student-teachers' textual and graphic explanations are analyzed on the followings levels: the student-teachers' structural and functional characteristics and their control process mental models. Findings and conclusions: It was found that student-teachers' mental models are partial, most of them have a structural model that contains only the visible components that are part of the operation unit and not the control unit. Moreover, their functional mental models are also missing. However, most of them explain the behavior of the system with rules (If…Then...) and as a sequential process (a,b,c…). From these findings, it is clear that a very systematic instruction unit must be developed to assist the student-teachers to construct their appropriate "runnable" mental models of a self-regulated system and PCK enabling them to teach this topic properly to their pupils.

Key words: Control mental models, Higher Education, Control Systems, Smart Artifacts, Pre-Service Teacher Training, Pedagogical Content Knowledge (PCK)

Introduction

Many systems all around us have smart control systems that behave according to their surroundings. They can adapt their behavior as their sensors sense the changes around them, for example: automatic doors, air-conditioners, smart ovens, etc. These control-smart (adaptive) systems can achieve a desired behavior while remaining in conditions of uncertainty.

Student-teachers who will teach this subject are expected to understand how these smart, adaptive systems work, possess the right mental models and PCK and be able assist their future pupils to construct their own mental models. It is crucial to analyze student-teachers' pre-mental models in order to design an appropriate instruction unit to prepare them.

There are only few studies on mental models of control systems among K-12 pupils and student-teachers. This paper presents a small study that supports earlier ones focused mainly on children (Koski & De Vries, 2013; Lind, et al., 2019; Mioduser et al. 1996) and less on student-teachers and active teachers (Hallström, & Klasander, 2017; Koski & De Vries, 2013; Slangen, Van Keulen & Gravemeijer, 2011; Svensson, & Klasander, 2012).

The current research found that student-teachers' control process mental models for everyday smart systems is partial; most of them have a structural model that contains only the visible components belonging to the operation unit and not the control unit. Their functional mental models are also lacking. However, most of them explain the behavior of the system with rules (If…Then…) and as a sequential process (a,b, c…). Their PCK is partial and insufficient for teaching.

The conclusions of this research reveal the need for an instructional unit on control that will address student-teachers' pre-perceptions. The outline of this instructional unit is presented.

Literature review

The literature review below relates to the concepts of control systems the mental models of them created by pupils and teachers and the teachers' knowledge.

Control systems

The technological systems in our everyday lives tend to be taken for granted and almost become invisible. There are systems with built-in self-regulating sub-systems acting as feedback loops, which are capable of modifying their own behavior to accommodate an unexpected change (Rzevski, 1995). The system regulates its behavior by comparing data from the environment (collected by sensors) to the desired output (algorithm in the controller) and sending instructions to the operators (light, motors etc.) to act in order to obtain the desired output.

Control systems are divided into two units: operation (OU) and control (CU) (Levin & Mioduser, 1996). The OU is further divided into two: the perception sub-system that collects data on the system and its environment state, and the execution sub-system that starts and stops the system operations. The control process – information (value of measures) collected by the perception sub-system received from the CU – is compared to the desired output by operating an algorithm. A decision on the continuing action is made and sent to the execution sub-system in order to obtain the desired output.

Pupils' and teachers' mental modeling of control systems

Mental models are internal cognitive representations of real-world situations that assist description, explanation and prediction (Norman, 1983). Mental models, including system mental models, are constructed during interactions between a person and a system step-by-step and in layered fashion (every day, over years and multiple interactions). This model changes and develops according to the knowledge one possesses while experiencing the system. This layered mental model is constructed from concrete to abstract to causal (Norman, 1983). A mental model is used to understand, explain, troubleshoot and improve a system or design a new one (Mioduser et al. 1996). Usually, a system's mental model is intuitive, partial and inaccurate, and people are limited in their ability to "run" it in their head in a way that matches reality (Norman, 2014). As a result, and given that technological systems are complex and hidden, their mental models tend to vary, often including misconceptions of how the different layers of the system work. Jones argued that 'the understanding of systems is essential in developing knowledge in technology.' (Jones 2003, p. 90). Research on technology system perceptions and particularly control systems is very limited for children and adults alike.

Studies on system understanding among primary-school pupils and teachers, found that a) the concept of input was clearer to pupils than output; b) the pupils had a linear conception of systems; c) the challenge was to differentiate between a process and a system, the role of information in the system and setting boundaries for the system; d) teachers need more knowledge about the similarities and differences between

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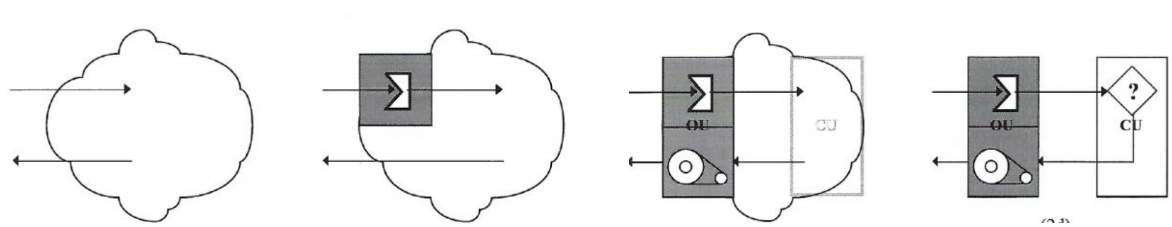
various technological systems and better understanding of system components and different layers; and e) teachers' mainly focused on system structure, input, process, output, and consequences for the environment (Lind et al. 2019; Koski & de Vries, 2013; Schooner, Klasander, & Hallström 2015; Slangen et al. 2011; Svensson & Klasander 2012).

Findings from research on student-teachers' perceptions of technology systems showed that a) most student-teachers could see the various parts in the system but were unable to connect them to a wider context; b) almost half the students provided answers that were considered undefined; c) the parts of the systems the students understood were mostly the visible ones (Hallström, & Klasander, 2018),

In addition, research investigating views of assessment of technological systems found that pupils are better at understanding the structure of a system than its behavior, control mechanisms and flow of information and they also better understand systems when they are scaffolded (Schooner, Klasander & Hallström, 2015).

Mioduser et al. (1996) investigated mental models that American middle-school pupils produce of control systems such as automatic doors, and household devices, before, during and after instruction. They studied pupils' 'conceptions, missing conceptions, and misconceptions' of these control systems. They developed a sequence of qualitative models of the control system consisting of four types of models, a) black-box – indicating that in the presence of input it produced an output; b) reactive – sensing functions are explicitly mentioned; c) switch – separate command-delivering functions appear; and d) control – control specifications are included (Figure 1).



Black Box Reactive Switch Control

Figure 1. Sequences of qualitative models of the control system (Mioduser et al. 1996 p.40)

Their conclusions were that the pupils' understanding prior to instruction was very poor (but slightly better after). They lacked accurate understanding of common components and how these affect the system. System structure was well understood, while control features of the system were poorly understood, as was the flow of information in the system (Mioduser, Venezky, & Gong 1996).

In recent years, studies have been conducted at Tel-Aviv University on kindergarten and primary school pupils' mental models of self-regulated systems. These studies found that kindergarten pupils understood the input unit, and that there are rules which determined the door's operation, but did not understand who really operates them. These misunderstandings led them to misconceptions and incorrect explanations (Rodan, 2016). The pupils' mental models do not include the CU, probably because it is invisible (as in Hallström & Klasander, 2017). Moreover, students' perceptions of control systems were based on 'Switch' and 'Control' (Landsman, 2019; Rodan, 2016).

Teachers' knowledge

Teaching requires basic skills, content knowledge and general pedagogical skills for effective teaching and begins with teacher's understanding of what is to be learned and how it is to be taught (Shulman. 1987 p.7). Based on Shulman's (1987) criteria of teacher's knowledge base, Grossman (1990) designed a model of teacher knowledge that includes: 1) SMK; 2) General PK; 3) Knowledge of context and 4) PCK. Shulman (1987) defined PCK as the amalgam of all the other domains. Researches show that teacher training should first focus on the development of teachers' SMK and then develop their PCK (Rohaan, 2012; Shulman, 1987; Slangen et al. 2011). In the current research, the adaptive control system is the PCK that contains structural, procedural and causal knowledge.

Based on this literature review, in this study, we examined the issue of what control system mental models student-teachers have.

Research question and method

The research question is: What are the student-teachers' mental models of control processes of control systems?
This question is subdivided into the following:

1. Do student-teachers give structural explanations (mentioning operational and control components)?
2. Do they give functional explanations (mentioning processes)?
3. How do they describe the control process?

Research participants were 37 female student-teachers attending a "Technology thinking and robotics" course in their pre-service studies for K-6 in 2018-2019. They will teach control systems as part of the mandatory Science and Technology curriculum. During this course, they need to develop their SMK and PCK of this subject and correct perceptions of control systems. In order to develop appropriate instruction, a survey of the student-teachers' prior mental models was conducted.

In order to answer the research question, participants were asked to describe how an automatic door works either by sketching or in writing. None of them explained it in writing only, %14 used only sketching without text and %86 used both. In most cases (84%), when the students used both text and sketches, they supported each other. The analysis was based on 37 student-teachers' sketches and on 32 texts (Table 1).

Table 1. The student-teachers' preferred mode of explaining 'how the control system works'

Text only	Sketch only	Both
0	14%	86%

Findings

The data were collected from the student-teachers' explanations of 'how an automatic door works'. Sketches and texts were analyzed according to the following criteria:

1. First question - structural explanations: mentioning components in their explanations, full/missing/extra structural model, use of OU and CU components (undefined/collection/coherent (control)).
2. Second question - functional explanations: mentioning aspects of how the system works, characteristics of the functional model (full/missing/extra).

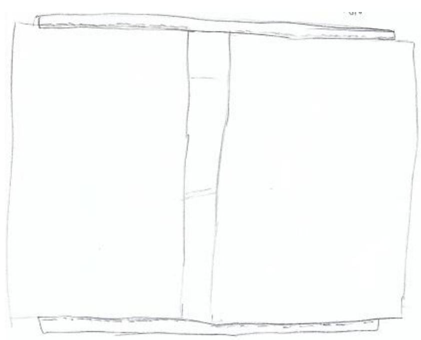
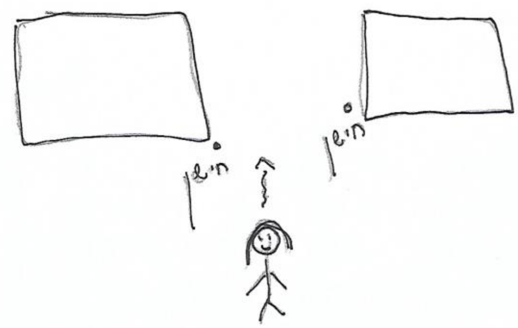
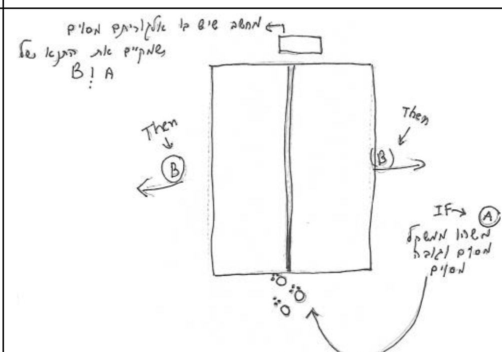
Third question - control process explanations: correct/incorrect, sequential/rules, and the perception of control (Black-box/Reactive/Switch/Control).  Structural: just one component (door), missing, undefined OU, CU. No functional model. Perception of control: 'Black-box'.	 Structural:Two components (door and sensor), missing, OU collection, undefined CU. Functional: using an arrow and person, missing. Perception of control: 'Switch'.
 Structural:Two components (door and sensor), missing and extra, OU collection, undefined CU. Functional: using an arrows and person, missing, Perception of control: 'Switch'.	 Structural:Three components (door, sensor and controller), missing, OU coherent, CU control. Functional: using arrows, full, sensor-> controller-> door. Perception of control: 'Control' and rule.

Figure 2. Examples of student-teachers' sketches analysis:

1) Structural descriptions

In testing the students' sketches and textual explanations on how the automatic door works, and analyzing them according to the categories and criteria, we understand that (a) most mentioned components in their explanations (0.97 of the sketches and all of them in writing); (b) most had missing components in their sketches (0.95) and in their texts (0.91); (c) only few mentioned all the components participating in the process (0.03 by sketch and 0.06 in writing); (d) some even added extra non-existent components that are not part of this system (0.14 in sketches and 0.22 in writing) e.g., signs, bicycles, trees etc. (see Table 2).

The students have better understanding of the OU components (using on average 1.92 components per sketch and 2.13 in their texts) than of the CU components (0.05 per sketches and 0.16 in texts).

It was not possible to analyze the OU and CU configuration from the student-teachers' sketches; this was based on their texts only. It was found that most of their OU configurations were collections (0.66) and their CU were undefined (0.84).

Table 2: The system structural mental model as presented by sketches and textual explanations

Category	**Criteria**	**Sketch**	**Text**
Structural	**components**		
	Mentioned components	0.97	1
	Full Missing Extra	0.03 0.95 0.14	0.06 0.91 0.22
	OU Existing components	71 average:1.92	68 average: 2.13
	CU Existing components	2 average 0.05	5 average: 0.16
	OU Configuration Undefined Collection Coherent		 0.16 0.66 0.19
	CU Configuration Undefined Collection Control		 0.84 0.13 0.06

Summary: the student-teachers' mental models structure for the automatic door contain some components (mostly sensor and door), that are from the OU, ignoring the CU components. Most student-teachers have a partial structure model of the OU configuration, and an undefined model of the CU.

2) Functional descriptions

The functional mental model answers the question of how the control system works.

Sketches did not give the whole picture of the functional mental models; however, the text explanations and the integration of both gave a better understanding. The analysis was made only on almost half the student-teachers' sketches (0.46) and on most texts - on 0.84. When analyzing those with functional explanations, many of them show a missing model (0.43 sketches, 0.75 texts), and only few from both sketches and texts showed full functional models (0.03, 0.09) (Table 3).

The text explanations show how the system works. More than half the students (0.66) explained that the sensor opens the door, others mentioned a sensor operating a motor (0.09) and the motor opening the door (0.06), a sensor to the controller (0.13) and the controller to the motor (0.03) or the door (0.09). Other student-teachers (0.19) explained that the door opens by itself.

Table 3: The system functional mental model as presented in sketches and textual explanations

Category	**Criteria**	**Sketch**	**Text**
Functional	Not functional	0.54	0.16
	Full	0.03	0.09
	Missing	0.43	0.75
	Extra	0.03	0.13
	The process		
	Sensor-doors		0.66
	Sensor- motor		0.09
	Sensor-controller		0.13
	Motor doors		0.06
	Controller-motor		0.03
	Controller-doors		0.09
	Other – doors, info, sensor		0.19

Summary: The functional mental models described both by sketch and in writing, are mostly missing models and focus on sensors that operate the doors. The mention of full control processes is very rare.

3) Control process explanations

The student teachers' explanations are mostly incorrect, and the process occurring in the CU has missing descriptions and components (0.81). However, half of them explained the process as "if…then", for example:

> **If** the sensor senses an object or a movement **then** the doors open to both sides (S.A.).

One-third of the students described the process as sequences, for example:

> a) the sensor identifies movement, b) the information is passed to the motor, c) the motor is activated,
> d) the doors move in both directions.. (G.B).

According to the 'sequences of qualitative models of the control system' categories (Mioduser et al., 1996), more than half the student-teachers' perceptions are 'Reactive' (0.59 by sketches and 0.66 in writing). Only 0.27 (sketches) and 0.16 (texts) have the 'Black box' model. The 'Switch' and the 'Control' models are very rare (see Table 4).

Table 4: The control system mental explanations as presented by sketches and textual explanations

Category	Criteria	Sketch	Text
Control models	Correct Incorrect (missing)		0.13 0.81
	Identifying the process None Sequential Rules		 0.16 0.34 0.50
	Perceptions of control process Black box Reactive Switch Control	 0.27 0.59 0.08 0.03	 0.16 0.66 0.09 0.09

The above analyses all draw the same picture of student-teachers' mental models of the automatic door as a representative of a control system. They recognized only few components (doors and sensors) from the OU. Most of them did not mention the CU or its components. More than half the students possess mostly missing functional models. Most students had incorrect control mental models, and yet the models were described by rules and sequences. Students have missing structural and functional models, as they lack information about the control process. This also manifests itself as most of them described 'Reactive' and 'Black box' models and not 'Switch' and 'Control' that reflect understanding of control processes. The instruction development is based on those student-teacher mental models that indicate their partial and incorrect SMK and PCK.

Discussion and implementations

The current research focused on the question: What are the student-teachers' mental models of control processes of daily life control systems? The students' explanations (sketches and text) indicated that for all the three layers (structural, functional and control process) most mental models are partial and include 'Reactive' perspectives that the sensor operates the doors or even when the sensor senses the doors open, or a 'Black box' perspective.

This research refines the understanding of control systems mental models by focusing on the student-teacher population. Student-teachers have only intuitive, partial and inaccurate models that limit their ability to "run" it in their head (Mioduser et al. 1996; Norman, 2014). Their models are structural and contain components; they hardly use the abstract aspects of systems, such as flow, boundaries, control etc. (Hallström & Klasander, 2017; Koski & DeVries, 2013; Lind et al. 2019; Rodan, 2016). It could be improved with appropriate teaching, experiencing and making the invisible visible (Hallström and Klasander, 2017; Mioduser et al. 1996). It was surprising that some studies on K-7 pupils showed that their mental models of controlled systems are based on 'Switch' and 'Control' (Landsman, 2019; Rodan, 2016) while in our research, the student-teachers' mental models (adults) were based only on 'Reactive' and 'Black box'.

It is crucial that these student-teachers have appropriate and accurate control systems mental models, SMK, CK and PCK that could assist their teaching (Shulman, 1987; Slangen et al. 2011; Rohaan et al. 2012). Studies that used the sequences of qualitative models of controlled systems (Mioduser et al., 1996) indicated that a systematic intervention program that involves building and programing the control system improves learners' mental models of control. Such scaffolding instruction programs could help the students' understanding of complex and invisible components and processes, and enable them to construct 'runnable' mental models of control (Hallström & Klasander, 2017; Landsman, 2019; Mioduser 1996).

It is crucial to develop an instructional curriculum that takes into consideration such research conclusions. The program would contain:

1. Scaffolding via teaching student-teachers to analyze systems with a variety of self-regulation control units and find similarities and differentiations (structural, functional and using rules) between systems.
2. Working with simulations that show transparent control systems and their flow of information and how they really work. Drawing conclusions from these simulations helps mental model construction.
3. Designing and making adaptive systems (e.g., using LEGO) and programming their behavior.

This research indicated that student-teachers who will teach technology and system control in K-6, have missing mental models and partial SMK and PCK. The following academic year, the improved control instruction will be delivered. Pre- and post-tests will be delivered and analyzed.

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