Evaluating an Intervention to Improve Secondary Pre-Service Teachers' Conceptions of Feedback in Technological Systems

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Feedback mechanisms make control of systems automatic and are thus inherent features of many technologies that surround us in our daily lives. Feedback is thus considered important to learn in technology education, although it is regarded as difficult and often not introduced to students until upper secondary level. Given the central role of feedback in technology and engineering it is surprising that there is virtually no research on how students of any age conceive of and/or learn about feedback in the technology and engineering education literature. The aim of this paper is to report on and evaluate an intervention to improve Swedish secondary pre-service technology student teachers' conceptions of feedback in technological systems. Five student teachers took part in the intervention, taking a pre-test prior to, and a post-test after, this intervention. Although this is a small sample, the findings indicate that the student group as a whole performed better in the post-test than in the pre-test. The findings also suggest that some teachers understood the systemic, macro aspects of feedback mechanisms better after the intervention. On the other hand, no student reached an expanded understanding, and most conceptions were rather vague. Furthermore, there was a general lack of atomistic conceptions, relating to a micro understanding, for example, sensors and how they work in a control system. This study thus confirms previous research about the lack of essential device knowledge among student teachers. Some implications for the continuation of the study are suggested based on these findings.

Keywords: student conception; micro understanding; macro understanding; feedback mechanism; technological system; technology teacher education

Introduction

Control theory is about controlling artefacts and systems and making them behave in the way we want them to (Glad & Ljung, 2000, 2006), by employing controllers and sensors for primarily negative feedback (see Appendix). Feedback mechanisms make control of systems automatic and are thus inherent features of many technologies that surround us in our daily lives, from the toaster to the home heating system to the municipal sewer system. Feedback is considered important to learn in technology education (Barak, 2018; Hacker, 2018) although it is regarded as difficult and often not introduced to students until upper secondary level (e.g. Goovaerts, De Cock, Struyven, & Dehaene, 2019; Martin, 1990). Some technology curriculum documents and standards for K-12 education thus include feedback (e.g. *Standards for Technological Literacy: Content for the Study of Technology*, 2007) whereas others only make implicit reference to it, for example, in relation to electronics, control systems, or programming (e.g. Australian Curriculum - Technologies, 2017; *Curriculum for the compulsory school, preschool class and school-age educare, revised 2018*, 2018; Technology in the New Zealand Curriculum, 2017).

Given the central role of feedback in technology and engineering it is surprising to note that there is virtually no research on how students of any age conceive of and/or learn about feedback in the technology and engineering education literature. There is a growing literature on conceptions and learning of feedback in social and natural systems (e.g. Booth Sweeney & Sterman, 2000, 2007; Gilissen, Knippels, Verhoeff, & van Joolingen, 2019; Hmelo-Silver & Azevedo, 2006). There are also studies in undergraduate engineering education where students are subjected to e.g. models of learning based on dynamic engineering systems (Eftekhar & Strong, 1999), or systems thinking interventions in engineering team-building (Walters, Greiner, O'Morrow, & Amadei, 2017) but very few deal with the learning of feedback in technological systems *per se*. One study, however, measured the perceived value of introducing a haptic joystick for undergraduate students in a course on dynamic systems and the students scored the highest on the use of the joystick in the labs about feedback control and virtual dynamic systems (Okamura, Richard, & Cutkosky, 2002). A few studies touch upon feedback more generally in school and technology teacher education and report on both children and adult students' difficulties in understanding flows of information and feedback loops in technological systems (Hallström & Klasander, 2017; Koski & de Vries, 2013). Mioduser, Venezky, and Gong (1996) conclude that in their study on middle school students' perceptions of control systems, the students "phrased the control laws in phenomenal or behavioral terms (what is observed), rather than in functional terms (how the system actually processes the information and produces outputs on acting components)" (p. 387). One of the underlying difficulties of understanding control features thus seems to be the fact that feedback loops are "invisible" in the sense that they are part of the flow of information in a technology or system, but more research is needed about this important yet under-researched area, not only on the students themselves but also their teachers.

The aim of this paper is to report on and evaluate an intervention to improve Swedish secondary pre-service technology student teachers' conceptions of feedback in technological systems.

Theoretical considerations and analytical framework

Cobern (1994) states that "[u]nderstanding is the epistemological or thinking process by which one comes to conceptual comprehension" (Cobern, 1994, p. 586). Prior to understanding something a person has different conceptions about the world, which may be more or less right, so any study engaged in students' or teachers' understanding of something first needs to analyze their conceptions (cf. Grosslight, Unger, Jay, & Smith, 1991). When studying conceptions, it is important to note that so-called misconceptions may not necessarily anticipate a poor understanding but could rather reflect an emergent technological understanding, depending on the context (e.g. Klasander, 2010).

The current study focuses on feedback as a curriculum component in secondary school and, more specifically, the teachers being trained to teach this content. This is why the intervention designed for the study – described in detail below – focuses on the student teachers' understanding of feedback. An analytical framework from a previous study about student teachers' understanding of technological systems on a more general level (Hallström & Klasander, 2017) was employed to specify the systems-related nature of the students' answers. Hallström and Klasander (2017) identify three distinct, qualitative categories of systems understanding: atomistic, systemic, and holistic conceptions. For this study, the first and second categories, *atomistic* and *systemic*, were considered especially in the analysis. Atomistic was made up of answers that reveal student conceptions of the parts or components in themselves, or that if one presses a button then something happens, without making the systemic connection or seeing flows of information, matter or energy in the system. Systemic, on the other hand, included a conception of flows and connections that make components into a system, as well as a conception of the physical extension of the system (with wires, cables, pipes etc.). Furthermore, this category included how the components interact more precisely and how flows of energy, matter, and particularly information, contribute to the working of the system, for example, through feedback loops (Hallström & Klasander, 2017, pp. 392-393).

As a way of describing the understanding of feedback in relation to the systemic and atomistic conceptions, I here introduce the concepts of *macro understanding* and *micro understanding* (cf. Barak, 2018; D'Alessandro, Johnson, Gray, & Carter, 2015) as two ways of coming to conceptual comprehension about feedback in technological systems. Macro (systemic) understanding concerns the basic, overall principles and features of feedback mechanisms such as the nature of negative and positive feedback and what role they play in different systems as well as how disturbances affect input, output and the stability of the system. The typical representation of understanding at this level is the general block diagrams of the flow of information or energy in a control system with feedback loop (cf. Su, Chien, Chen, & Wang, 2006). The micro (atomistic) understanding, on the other hand, concerns the component parts of the control systems with feedback loops, that is, what the central components are, their purpose and how they are connected (control unit/regulator, sensors, etc., represented with more detailed block/system diagrams). A full understanding of feedback mechanisms requires both a macro and a micro understanding, in line with classic cybernetics and control theory (cf. Hughes, 2004; Thomas, 2016; Wiener, 1950/1989). However, what the nature of these two types of understanding is in the context of technology teacher education is expected to be an outcome of this study.

Methodology

Participants

The study was conducted at a Swedish university with student teachers studying to get a teacher degree in technology education, and one or two other subjects (mathematics education, educational sloyd, and/or science education). Four students studied for a teacher degree for lower secondary education (grades 7-9) and one student for upper secondary education (grades 10-12). All five students took part in the first cycle of the study reported in this paper. This cycle included a pre-test carried out in the first session of an undergraduate course about teaching and learning about technological systems. A minor electable control theory component (excluding feedback) had been part of an earlier course, but in principle the pre-test was designed to capture the students' conceptions of technological systems and feedback before they had had any teaching about this, and before the intervention which was included as part of the current course. The post-test was carried out with four of the five students after finishing the course, and thus after having gone through the intervention (one of the students was ill when the test was taken).

Intervention and data collection

The intervention consisted of a two-hour seminar, including a mini-lecture by the researcher, about feedback in technological systems. The mini-lecture and seminar were based upon a short text about feedback written by the researcher, "Feedback in technological systems", specifically promoting a macro and micro understanding of feedback (see Appendix for an abridged English version of the Swedish original). Furthermore, the intervention included a conference paper on the utilization of system models/block diagrams in learning about technological systems (Hallström, Klasander, & Svensson, 2015) and a short, quite standardized textbook section about control systems and feedback for technology teachers in secondary education (Grimvall, 2014, pp. 127-133). The students were told to read the short researcher text as well as the paper and textbook section before the seminar so as to learn the appropriate concepts and to be prepared to discuss and ask questions about feedback at the seminar.

Data was collected before (pre-test) and after (post-test) the intervention through a questionnaire with two open-ended questions: "According to you, what is a technological system?" and "According to you, what is *feedback* in a technological system?". Only answers to the second question were analyzed as part of this paper.

Data analysis

The collected data from the pre- and post-tests was transcribed and subsequently analyzed, coded and categorized in Swedish. The method of analysis is qualitative and hermeneutic, using thematic analysis in line with how Braun and Clarke (2006) describe the method in six phases. The initial two phases were to familiarize oneself with the data, which included repeated reading of the entire dataset, and second, to generate initial codes, which meant that any text section relating to the aim of the research was labelled with a descriptive code. Each labelled text section contained approximately two to five sentences. These two phases were performed inductively, to find comprehensive patterns in the data. The third phase included the generation of themes, which first of all meant sorting the codes into a hierarchical order. The themes were then generated deductively in the sense that conceptions about feedback that could be construed as *atomistic* and *systemic* were highlighted and further explored (Hallström & Klasander, 2017). The subsequent fourth phase meant revising and refining themes in order to minimize overlap between them. The fifth phase consisted of defining and naming themes where it was found that they included aspects of students' conceptions that aligned with the analytical concepts mentioned above. The sixth phase was to compile exemplary data and quotes to exemplify the themes and include them in the presentation in the Findings section (Braun & Clarke, 2006). The quotes should be seen as representative examples of the themes, not as quantitative representations.

Validity and Research Ethics

The findings reflect a collective total picture of how the student teachers conceive of feedback loops. The results of the study are thus the researcher's interpretation of the students' conceptions on a collective level. The data from five students constitute a limited data set, but as is shown, it is enough to validate the themes, draw a few conclusions, and suggest some implications for future research. The results can, in a strict sense, only be seen as representative of the five students, but the hope is to generate an intersubjective understanding of technology student teachers' conceptions through them. That is, the results of this study point to possible conceptions of feedback in technological systems that pre-service teachers may have, even beyond the Swedish context.

The pre-service student teachers, who were all above 18 years of age, were informed about the main outline and purpose of the study, and that it was voluntary to participate and that they therefore could discontinue any time they wanted. Furthermore, they were informed of the fact that their answers would be anonymized, and that the data will only be used for research purposes. They all expressed consent to participation and that their answers on the tests could be used as research data, by signing a written document to that effect (Robson & McCartan, 2016).

Findings

The student responses were categorized so as to account for the qualitative elaboration of the conceptions of feedback, in relation to both atomistic and systemic conceptions. New themes/conceptions were thus constructed and came to be labelled *limited*, *intermediate* and *expanded* in relation to the potential for understanding feedback. (A fourth theme, undefined, meant that any hint of a conception of a system, or a feedback loop, was lacking, or deemed unintelligible.) Limited means that one can distinguish a very rudimentary conception of a feedback loop; information is fed back into the system automatically to control it in some way. For intermediate a feedback loop is described as a way of automatically controlling a system by feeding back information, by way of sensors, into the system so that disturbances in the system's performance can be corrected. Negative feedback reduces fluctuations in the system's performance. For the conception expanded there is the more elaborate notion that the system is controlled by way of a control unit that, based on the information from sensors, corrects the input (set point) in order to get the desirable output (process value); if there is a disturbance, sensors feed back information to the control unit which then automatically adjusts the information accordingly so that the system performs its function with less and less fluctuation (negative feedback).

Pre-test

As could be expected, when the students did the pre-test before starting the intervention, the overall understanding of feedback in technological systems was weak. Of the five students, three students' conceptions were considered limited, and two as undefined. One example of a limited conception was one which included the central control theory concepts of set point and process value but not much else:

> Feedback in a technological system is when the process value is compared to the set point, and the system is then adjusted to this so that the process value comes closer to the set point.

This conception was considered limited because, although the right concepts were used and it was systemic (a system is hinted to), neither the system nor its components were clearly described, nor how the system could adjust the process value by way of information from sensors. Another example was similarly labelled as limited, but for almost the opposite reason:

> Feedback in a technological system may be when the various components in the system communicate with each other, "back and forth", in a kind of feedback, to improve the function of the system.

The above quote expresses a more atomistic conception, although a system consisting of components that communicate and feed back information in order to control it is alluded to. However, a feedback loop and important feedback concepts are missing as are, for example, any mention of sensors (e.g. Goovaerts et al., 2019; Thomas, 2016). Below is one example of an undefined response:

> In the same way that control technology uses control to send back information from the system, feedback is needed in a technological system in order to make necessary changes in the system.

What this quote basically says is that feedback is the same as feedback. Also, while feedback indeed causes changes in the system, the direction of the feedback and the changes it causes are not specified.

Post-test

There was a slight improvement of student understanding of feedback from the pre-test to the post-test, in that of all the responses three were labelled limited and one intermediate. An example of a post-test limited response, bordering on intermediate, is the following: it constitutes a rudimentary conception of a feedback loop and vaguely specifies a component/sensor:

> In a feedback loop information is given to earlier steps in the system. For instance, in district heating there are sub-stations that measure pressure and other kinds of information which then regulate the system so that the output is being kept invariant.

Another example of a more systemic limited conception is when a student defined feedback as "a way of controlling the system. Feedback can be found in different parts of systems." The student also drew a block diagram of input → process → output with a feedback loop, a system model which was introduced in the intervention but with more details and complexity regarding how negative feedback is achieved (see Appendix and Grimvall, 2014). Yet another limited student response exemplified feedback with a water closet and how after flushing the tank is filled automatically, but the student failed to explain how the float acts as a sensor in such sequential control (Figure 1).

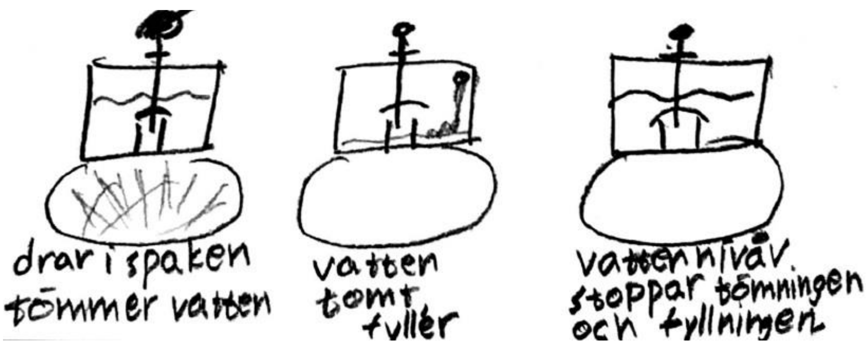


Figure 1. Student-generated image of the flushing of a water closet as example of feedback

The student expressing an intermediate conception correctly represented the systemic perspective in the form of the block diagram of how a feedback loop works (Figure 2).

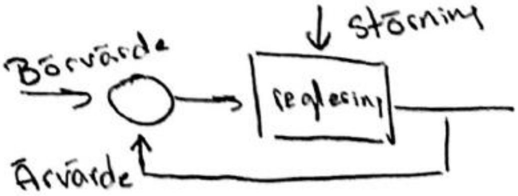


Figure 2. Student-generated block diagram of a simple feedback loop

The student also wrote:

> Positive/negative feedback, when “disturbance” happens in the system, components feed back in order to “stabilize” after “disturbance”. For example, a change in the flow of matter, energy or information may require feedback for the flow to be able to continue circling in the system.

Thus, this student also expressed an atomistic conception detailing components/sensors, although it was rather vague.

Concluding Discussion and Implications

The pre-service teachers taking part in this study had little or no prior knowledge of technological systems, control theory or feedback loops, so the fact that the group as a whole performed better in the post-test than in the pre-test is not surprising. Although this is a small sample, the findings indicate that some teachers understood the systemic aspects of feedback mechanisms, especially after the intervention. The systemic, or macro level of understanding control systems and feedback has to do with the basic principles of feedback, as described in the basic block diagram that was part of the intervention (see Appendix). On the one hand, this could indicate that the intervention was successful for some students, especially since the basic principles of feedback are considered difficult to understand (Goovaerts, De Cock, Struyven, & Dehaene, 2019; Martin, 1990). On the other hand, no student reached an expanded understanding, and most conceptions were rather vague. Furthermore, there was a general lack of atomistic conceptions, relating to a micro understanding. For example, although several students could at least vaguely express the basic principles of feedback, few could pinpoint sensors, how they work and their role in a control system. This study thus confirms findings of Mioduser et al. (1996) and Hallström and Klasander (2017) about the lack of essential *device knowledge* among both adult student teachers and school students.

An implication of this first cycle of the research project is consequently that for the subsequent cycle the preservice teachers may need to be trained more in device knowledge and atomistic conceptions of control systems, that is, how the various component parts work together for feedback to work. The students could, for example, be tasked to design their own control systems. Furthermore, since the students really need to develop both their macro and micro understanding another way of developing the intervention might be to have students use more detailed and elaborated block diagrams (Thomas, 2016), something which they would need in the design task anyway. Finally, the mathematics involved in feedback in simple, static control systems, e.g. proportional feedback, and, further, in dynamic systems, may also be introduced since this forces students to reflect on both micro and macro level aspects of such systems/feedback. Discussion of complex control problems and rules of thumb may also ensue (Glad & Ljung, 2006; Norström, 2014). A well-developed understanding of feedback needs to be at both a macro and micro level in order to incorporate the complexity of such understanding.

Appendix

What is feedback?

Feedback features in all kinds of systems. An everyday example is the sale of milk cartons in a grocery store. The inflow in this milk sale system is controlled by the milk orders from the grocery store, and the shop keeper is a kind of "sensor" which monitors the stock of milk cartons. The system is controlled towards an optimal stock that matches the demand for milk, and so the feedback has a dampening effect. This is called *negative feedback*. An example of *positive feedback* is when many people in a room are talking at the same time, and each person needs to raise their voice little by little, in order to be heard. This leads to an amplifying effect, the opposite of a dampening effect (cf. Levary, 1986). The most common form of feedback in technological systems, however, is negative feedback, so that is what we focus here. Feedback in a technological system is thus a way of controlling it with sensors that feed back information to the system's control unit (Mioduser et al., 1996). Below is a way of describing the *flow of information* in a feedback loop in a technological system (Figure 3):

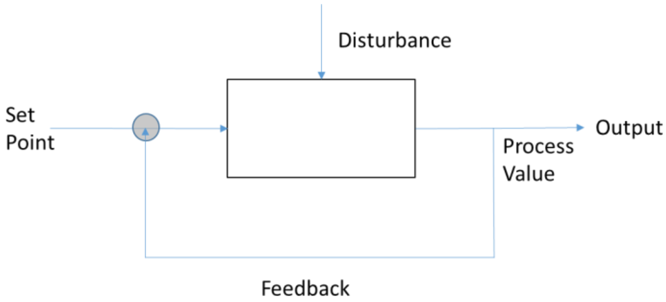
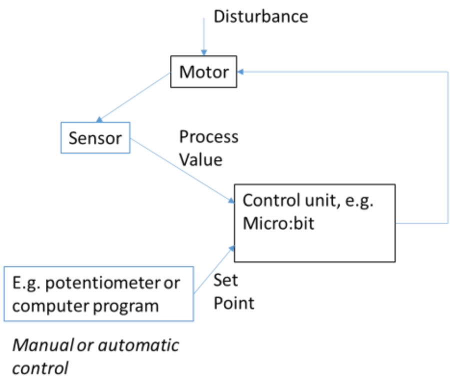


Figure 3. Block diagram/system model of the flow of information in a feedback loop.
Source: inspired by Grimvall (2014), p. 129.

What does feedback look like in different technological systems?

When describing in more detail how feedback mechanisms are designed in technological systems, one cannot rely only on the above block diagram (Figure 3) because it merely shows the flow of information and how it contributes to the control of the system. A technological system with feedback loops can be designed in various ways and have many different types of flows, both of information (e.g. the Internet), matter (e.g. water supply) and energy (e.g. electric grids). Below is a system diagram of a simple control system with feedback (Figure 4) in which the focus is on how the system is physically connected to achieve control.
Figure 4. System diagram of a simple control system with manual or automatic feedback



The motor speed is fed back to the control unit, with possible manual control using a potentiometer or automatic control employing a computer program. Information about disturbance, for instance, something hindering the rotation of the motor, is fed back through the sensor and it can be adjusted manually or automatically by increasing the speed via the control unit.

References

Australian Curriculum - Technologies. (2017). Retrieved from https://www.australiancurriculum.edu.au/, 6/12/2019.

Barak, M. (2018). Teaching Electronics: From Building Circuits to Systems Thinking and Programming. In M. J. De Vries (Ed.), *Handbook of Technology Education* (pp. 337-360). Cham: Springer.

Booth Sweeney, L., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review, 16*(4), 249-286.

Booth Sweeney, L., & Sterman, J. D. (2007). Thinking about systems: student and teacher conceptions of natural and social systems. *System Dynamics Review, 23*(2/3), 285-312.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77-101.

Cobern, W. W. (1994). Point: Belief, Understanding, and the Teaching of Evolution. *Journal of Research in Science Teaching, 31*(5), 583-590.

Curriculum for the compulsory school, preschool class and school-age educare, revised 2018. (2018). Stockholm: National Agency for Education.

D'Alessandro, S., Johnson, L., Gray, D. M., & Carter, L. (2015). The market performance indicator: a macro understanding of service provider switching. *Journal of Services Marketing, 29*(4), 302-313.

Eftekhar, N., & Strong, D. R. (1999). Towards Dynamic Modeling of a Teaching/Learning Process Part 3: The Simulation Model. *International Journal of Engineering Education, 15*(3), 168-190.

Gilissen, M. G., Knippels, M. C. P., Verhoeff, R. P., & van Joolingen, W. R. (2019). Teachers' and educators' perspectives on systems thinking and its implementation in Dutch biology education. *Journal of Biological Education*, 1-12, doi:10.1080/00219266.2019.1609564.

Glad, T., & Ljung, L. (2000). *Control Theory: Multivariable and Nonlinear Methods*. London & New York: Taylor & Francis.

Glad, T., & Ljung, L. (2006). *Reglerteknik. Grundläggande teori*. Lund: Studentlitteratur.

Goovaerts, L., De Cock, M., Struyven, K., & Dehaene, W. (2019). A Concrete Proposal to Introduce Control Theory to 16 Year Old Pupils. *European Journal of STEM Education, 4*(1), 1-11.

Grimvall, G. (2014). *Teknikens metoder. Skolans teknikämne i senare skolår*. Lund: Studentlitteratur.

Grosslight, L., Unger, C., Jay, E., & Smith, C. L. (1991). Understanding Models and their Use in Science: Conceptions of Middle and High School Students and Experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Hacker, M. (2018). Engineering and Technology Concepts: Key Ideas That Students Should Understand. In M. J. De Vries (Ed.), *Handbook of Technology Education* (pp. 173-192). Cham: Springer.

Hallström, J., & Klasander, C. (2017). Visible parts, invisible whole: Swedish technology student teachers' conceptions about technological systems. *International Journal of Technology and Design Education, 27*(3), 387-405.

Hallström, J., Klasander, C., & Svensson, M. (2015). The Black Box and Beyond: Introducing a Conceptual Model as a Learning Tool for Developing Knowledge about Technological Systems. In M. Chatoney (Ed.), *PATT 29 Plurality and Complementarity of Approaches in Design & Technology Education, Marseille, France, April 2015*. Marseille: Presses Universitaires de Provence.

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the Learning Sciences, 15*(1), 53-61.

Hughes, T. P. (2004). *Human-built world: How to think about technology and culture*. Chicago: University of Chicago Press.

Klasander, C. (2010). *Talet om tekniska system. Förväntningar, traditioner och skolverkligheter*. Norrköping: Linköpings universitet.

Koski, M.-I., & de Vries, M. J. (2013). An exploratory study on how primary pupils approach systems. *International Journal of Technology and Design Education, 23*(4), 835-848.

Levary, R.R. (1986). Simulation as a Tool for the Analysis and Design of Systems. *European Journal of Engineering Education, 11*(2), 165-176.

Martin, D. J. (1990). Stages in systems thinking, modelling and realisation in school electronics. *International Journal of Technology and Design Education, 1*(1), 14-20.

Mioduser, D., Venezky, R. L., & Gong, B. (1996). Students' Perceptions and Designs of Simple Control Systems. *Computers in Human Behavior*, *12*(3), 363-388.

Norström, P. (2014). *Technological Knowledge and Technology Education* (diss). Stockholm: Royal Institute of Technology (KTH).

Okamura, A. M., Richard, C., & Cutkosky, M. R. (2002). Feeling is Believing: Using a Force-Feedback Joystick to Teach Dynamic Systems. *Journal of Engineering Education, 91*(3), 345-349.

Robson, C., & McCartan, K. (2016). *Real World Research: A Resource for Users of Social Research Methods in Applied Settings* (4th ed.). Chichester: Wiley.

Standards for Technological Literacy: Content for the Study of Technology. (2007). (3rd ed.). Reston, VA: International Technology Education Association.

Su, J.-H., Chien, C.-L., Chen, J.-J., & Wang, C.-M. (2006). Simulink behavior models for DC-DC switching converter circuits using PWM control ICs. *International Journal of Engineering Education*, *22*(2), 315-322.

Technology in the New Zealand Curriculum. (2017). Retrieved from http://nzcurriculum.tki.org.nz/, 6/12/2019.

Thomas, B. (2016). *Modern reglerteknik*. Stockholm: Liber.

Walters, J. P., Greiner, B., O'Morrow, E., & Amadei, B. (2017). Fostering Systems Thinking within Engineers Without Borders Student Teams Using Group Model Building. *International Journal of Engineering Education*, *33*(1), 247-260.

Wiener, N. (1950/1989). *The Human Use of Human Beings: Cybernetics and Society*. London: Free Association Books.

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