Guidelines for Learning Material That Foster Students' Feedback Systems Thinking in Secondary School Biology Education

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Abstract

Systems are present everywhere, examples are cells and organisms. In order to understand systems, systems thinking is required. Despite the increasing importance of systems thinking in biology education, it is not regularly integrated into the curriculum by Dutch teachers, which leads to students experiencing difficulties. For instance, students have difficulties with identifying feedback mechanisms, even though control loops consisting of a feedback mechanism are common in biology education. The focus of this study was on tools to foster students' identification and understanding of control loops. To achieve this, the effectiveness of a pre-determined set of guidelines was determined. The set of guidelines consisted of four theory-based guidelines, namely: let students focus on the components and its functions, the relationships, and the feedback mechanism of control loops. These guidelines were meant to foster students' ability to identify and understand control loops, also referred to as feedback systems thinking. This consists of three skills: identifying structure and relationships of control loops, and understanding its feedback mechanism. The following research question was proposed: What are guidelines for learning material that foster students' feedback systems thinking in secondary school biology education? A quasi-experimental research with 37 students (14-17 years old) was conducted to determine the effectiveness of the guidelines. Results indicate that the guidelines resulted in students identifying the structure and the relationships of control loops more often. However, students did not show increased understanding of the feedback mechanism. This study suggests that the four guidelines as a whole is promising in fostering students' feedback systems thinking to the extent of identification of control loops.

Key-words: systems thinking; control loops; guidelines; learning material; biology education; secondary school

Introduction

The human body consists of several systems. A few examples of biological systems are cells, tissues, and organs. However, systems are not only restricted to the human body. Systems are present everywhere. An ecosystem and a computer are also examples of systems. According to Raved and Yarden (2014, p.1), “A system is a collection of components and/or processes.”. An interesting feature of a system is that it can be part of another system. For example, an organism is itself a system, but it is also part of other systems, such as a population, an ecosystem, and the biosphere. Besides this, biological systems are multileveled systems, which means that they consist of numerous different components, nonlinear relationships, and dynamic processes including feedback mechanisms (Brandstädter et al., 2012; Tripto et al., 2013). In order to identify and understand complex and dynamic systems, systems thinking is required (Evagorou et al., 2009). Systems thinking consists of several systems thinking skills. There are various lists of characteristics of systems thinking and systems thinking skills (Assaraf et al., 2013; Verhoeff et al., 2008; Hmelo-Silver et al., 2007). For example, Assaraf et al. (2013) suggested a model that is arranged in ascending levels of system thinking skills. A low level skill is the identification of the system’s components. A high level skill is making generalizations about a system and identifying its patterns, such as hierarchy, homeostasis, and dynamism.

Over the years, there has been a greater emphasis in research on systems thinking and its importance in biology education. The Dutch exam program (2017) for biology also supports the importance of systems thinking. In literature, a remarkable amount of studies that has been carried out so far mainly made use of materials, such as computer-based simulations, computer modeling, or an extensive program (e.g. several hours of direct instruction and practical’s) to develop or assess systems thinking (Verhoeff et al., 2013; Assaraf and Orion, 2005; Sweeney & Sternman, 2007;

Riess & Mischo, 2010). These kinds of materials are commonly used to assess students' prior knowledge of what systems are, how they function, and how they represent the dynamics of systems (Tripto et al., 2013; Assaraf & Orion. 2005). However, it seems that these approaches have several disadvantages. Students can lose contact with the real-life situations when they are busy modeling (Westra, 2008). Another disadvantage is that materials are time-consuming to implement and use, while teachers already struggle with a shortage of time (Westra, 2008). Lastly, these materials cannot easily be incorporated into an already full curriculum. This means that despite the increasing importance of systems thinking in biology education, it is only integrated to a limited extent into secondary biology education (Brandstädter et al., 2012).

The lean integration of systems thinking means that the focus of biology education is on events rather than gradual processes, on components instead of systems as a whole, and on isolated processes instead of systemic relationships (Evagorou et al., 2009). The deficiencies in integrating systems thinking within biology education lead to students having difficulties identifying and understanding systems (Evagorou et al., 2009).

Students experience great difficulties especially in developing advanced system thinking skills (Evagorou et al., 2009). For example, students struggle to identify and understand feedback mechanisms, even though systems that self-regulate through control loops are commonly taught in secondary biology education, such as the systems that help maintain homeostasis. It would be better for students if the teachers exposed students more often to the presence of systems and let them regularly use systems thinking (Assaraf et al., 2013).

From the preliminary results of Ph.D. candidate M.G.R. (2018), it seems that teachers only occasionally pay attention to systems thinking instead of explicitly focusing on it, while system thinking takes time to master and therefore has to constantly return in biology education. In addition, it also appears to be important to explicitly teach students about system thinking and to teach them a systems language. From the preliminary results, it also appears that the lean attention and integration of systems thinking may be due to teachers having a lack of tools that are simple, not very time consuming, and easy to integrate into the biology curriculum. This results in a situation where teachers do not know how to implement systems thinking in their teaching practice multiple time throughout the year and also do not have tools to support them.

Due to the abundance of control loops in biology education, students' difficulties, and the lack of tools for teachers, the focus of this study is on tools to foster students' understanding of control loops. To achieve this, the effectiveness of a pre-determined set of guidelines will be determined. The set of guidelines consisted of four theory-based guidelines, namely: let students focus on the components and its functions, the relationships, and the feedback mechanism of control loops. These guidelines are meant to foster students' ability to identify and understand control loops, also referred to as feedback systems thinking. For students to foster feedback systems thinking, they need to be able to identify the structure of a control loop (skill 1), to identify the relationships between the components (skill 2), and need to understand the feedback mechanism that enables control loops to regulate itself (skill 3). The aim of this study is to determine what guidelines are for learning material to foster students' feedback systems thinking. Therefore the following research question is proposed:

What are guidelines for learning material that foster students' feedback systems thinking in secondary school biology education?

Theoretical background

Systems

The abundance and diversity of systems lead to different disciplines (e.g. biology, physics, and economics) having various perspectives on systems and its dynamics. In literature, several definitions of biological systems are proposed, such as: “A system is an entity that maintains its existence and functions as a whole through the interaction of its components.” (Raved & Yarden, 2014, p. 1). This definition emphasizes the significance of the interactions between systemic components. For students to interpret and understand systems it is essential that they are able to recognize the characteristics of biological systems. Additionally, Boersma et al. (2011) described nine characteristics of the dynamic behavior of biological systems, which are:

1. Systems have an identity and a distinct systems boundary.
2. Systems consist of different components that occur on different levels of biological organization.
3. Components of systems perform functions.
4. There is an interaction between the different components of the system.
5. There are open and closed systems; there are only exchanges between open systems and the environment.
6. Open systems have an input and output of matter, energy or information.
7. Systems are self-regulated by feedback mechanisms to maintain original or mean values.
8. Open systems are self-organizing systems with emergent properties resulting from interaction between system components.
9. Systems have one or more temporary phases of equilibrium, which make the transition to chaotic phases and then to new equilibrium states.

In this study, the focus is on control loops that enable biological systems to regulate themselves. Control loops consist of several components with each having its own specific function (for example, receptors measure the amount of a substance). The components interact with each other and that enables control loops to self-regulate themselves by the feedback mechanism.

Control loops.

Control loops are abundant in the human body, such as the regulation of body temperature, metabolism, the glucose level, and carbon dioxide level in blood. These are examples of values that need to be regulated strictly within the human body (McGraw-Hill College Division, 1997; Comar & Bronner, 1960). In literature, there are different representations of control loops. For this study, the model of Cybernetics is used (see Figure 1). This because the model corresponds with the general control loop in Dutch biology textbooks. The Cybernetics is a systems theory in which homeostasis and the feedback mechanism are the central concepts. Homeostasis is the process that keeps the internal environment of the body (blood plasma and tissue fluid) constant, or in other words, stable.

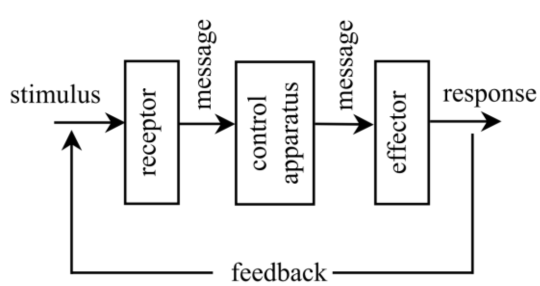

Figure 1. The representation of a system according to the theory of Cybernetics (Verhoeff, 2003).

The above representation shows the systems' components and their relationships to each other, for example, the relationship between the response and the stimulus, which is referred to as the feedback loop.

According to the theory of Cybernetics, living systems can maintain homeostasis because of the ability of self-regulation. In order for living systems to maintain a homeostasis through self-regulation, biological systems possess control loops consisting of feedback mechanism (see Figure 1) (Verhoeff, 2003). The feedback mechanism ensures that values stay within a very small range of variation despite wide fluctuations in its activity and in the external environment (Comar & Bronner, 1960; Verhoeff, 2013). Each component of a control loop has a specific function for self-regulation. In addition, the relationships between the components play an essential role. For example, the internal environment is measured by receptors and then compared with the desired value, also known as the setpoint value, in the control apparatus (e.g. the brain). When the measured value exceeds the set point, signals are sent to effectors which are organs, in order to recover the internal environment back to its setpoint. It is the negative feedback mechanism that recovers the exceeded value of a system back to the setpoint value. This mechanism enables the response of a system to inhibit the stimulus (see Figure 1) (Verhoeff, 2003).

Systems Thinking

In order for students to be able to understand systems with control loops, they require systems thinking. Systems thinking consists of different skills, however, there is no general list specifying these skills in literature. A variety of studies focused on different aspects of systems thinking skills. For example, the model of Assaraf et al. (2013) consists of three levels, increasing in difficulty. The first level is an analysis of systems’ components. This means that students should be able to identify the components and the processes. The second level is the synthesis of systems’ components, which means that students should be able to identify dynamic relations within a system. The third level is the implementation level and relates to the ability to generalize and identify patterns in a system.

In contrast, according to Verhoeff et al. (2008), system thinking is a competence that can be classified into four components. Researchers use the following definition for competence: "A competence is the combined action of attitude, knowledge, and skills that enable to perform a task adequately and must be meaningful and functional in one or more real-life activities or settings." (p. 3). The four components are:

- Being able to distinguish different levels of biological organization and to match biological concepts to specific levels of biological organization.
- Horizontal coherence: being able to interrelate concepts at a specific level of the organization.
- Vertical coherence: being able to link biology concepts from different levels of organization.
- Being able to think back and forth between abstract visualizations and concrete real biological phenomena.

The last example is the structure-behavior-function theory of Hmelo-Silver et al. (2007). This theory concentrates on causative relationships between structures, behavior and the functioning of a system. The structures are the components of a system, which can be divided into a micro-level and macro-level. Taking into consideration that there is great variety between biological systems, components can differ in in size and organization (Hmelo-Silver et al., 2007). The behaviors are the mechanism, or 'how', of a system. In other words, how the structures of a system collectively achieve an outcome or a function. The functions are the 'why' of a system, which refers to the role or roles of components in a system. These three components are interrelated, which means that structure, behavior, and function can influence each other. For example, a change in the components of a system can positively or negatively influence the function. The effects on the function can be predictable (Hmelo-Silver, 2007).

The various studies show systems thinking and systems thinking skills from different perspectives. Despite the differences between the studies, there are similarities on a general level. For example, all three studies mention the systems' components and the relationships between the components. These points are also present in this study where the focus is on biological systems that are able to regulate themselves through control loops. In order for students to identify and understand control loops, they require feedback systems thinking which is a combination of three skills. Skill 1 is identifying the structure of a control loop that consists of different components. Skill 2 is identifying the relationships between the components within a control loop. Lastly, skill 3 is understanding the feedback mechanism which enables control loops to regulate itself. These three skills correspond with those of Assaraf et al. (2013) because here the skills increase in difficulty as well. For example, skill 1 is equal to the first level of Assaraf et Al (2013) which is an analysis of systems' components. Skill 3 corresponds with level 3 which is the ability to generalize and identify patterns in a system.

Current Studies on Feedback Mechanisms

There is a broad range of studies regarding system thinking and system thinking skills. Some studies aim to assess the systems thinking skills of the participants, others aim to develop or promote systems thinking skills. Depending on the study, the focus is on one or more skills. Looking at the different system thinking skills, it is apparent from multiple studies that skills associated with control loops and feedback mechanism are less or not at all fostered in comparison to other skills (e.g. identification of the components and the relationships between them) (Verhoeff et al., 2013; Assaraf and Orion, 2005; Sweeney & Sternman, 2007; Riess & Mischo, 2010). For example, the study of Hogan (2000) analyzed students' systems reasoning about food web perturbations and pollutant effects within ecosystems. The study consisted of a test unit that lasted a month where students constructed, observed, and manipulated mini-ecosystems. Before and after completing the unit, the students had a paper/pencil task and participated in a constructive interview. The results of the study indicated that students reasoned mostly linear about the perturbations within a food web instead of cyclic reasoning. The small number of students who identified cyclic patterns within the food web had a limited recognition of feedback mechanisms. This means that a limited number of students recognized that the output of a system influences the input.

Another example is the study of Sweeney and Sternman (2007). They developed the Systems-Based Inquiry protocol to surface participants' intuitive models of complex system dynamics. The researchers looked into the reasons why not more participants naturally incorporated feedback processes in their reasoning. A possible reason was that people tend to focus on one-way causal structures while more complex interaction patterns exist. Another possible explanation is that the term 'feedback' has several meanings, which can create difficulties in using the term correctly. Lastly, participants can use terms such as 'cycle' and 'chain' instead of the term 'feedback' for describing the present feedback. These terms are not always approved. In the study Sweeney and Sternman (2017), however, terms as 'cycle' and 'chain' were accepted as a way to show recognition of feedback structures.

Despite the efforts of the researchers, they were only to a limited extent able to develop or promote students' systems thinking skills regarding the feedback mechanism. For this study, it is important to take the findings from the different studies into account. The findings lead to two important points. Firstly, when students use terms such as 'cycle', they do show recognition of the feedback. Secondly, students mostly reason in a linear way instead of circular, while control loops are circular. For students to be able to identify and understand control loops they need to reason in a circular way. This could be done by promoting cyclic reasoning through learning activities (e.g. causal loop diagrams).

Guidelines for Learning Material

In order for learning material to foster students' feedback systems thinking, guidelines for this material should be determined and formulated. For students to be able to identify and understand control loops, they need to identify and understand the main characteristics of control loops. Therefore the guidelines focus on the main characteristics of control loops. As mentioned before, Assaraf et al. (2013) developed a hierarchal model of eight characteristics of systems thinking divided into three stages by which system thinking develops. The three levels are an analysis of system components (identifying the components); synthesis of system components (e.g. identifying the relationships between the components); and implementation (e.g. making generalizations about a system and identifying patterns such as homeostasis). Each group of skills (each level) is used as the basis for the development of the skills needed for the next level. Therefore, for students to be able to achieve the highest level of systems thinking, which in this case is the identification and understanding of feedback mechanisms, they first need to identify the structure and the relationships of control loops. Therefore, for this study, three main characteristics of control loops were determined, which are the structure (components and their function), the relationships, and self-regulation. By letting students first identify the structure and relationships of control loops, students have a basis for the understanding the feedback mechanism. Based on the characteristics of control loops the researcher formulated four guidelines for learning material (see Table 1).

Table 1. Arranged guidelines for learning material to foster students' feedback systems thinking. These guidelines are formulated based on the main characteristics of control loops.

Characteristics of control loops	**Guidelines for learning material**
Structure	1. Let students focus on the components.
	2. Let students describe the function of the components.
Relationships	3. Let students identify the relationships between the components.
Self-regulation	4. Let students focus on the presence of a feedback mechanism.

Design of the Learning Material

The researcher converted the four guidelines into guided steps. The guided steps are instructions for the students that aim to provide guidance in identifying and understanding control loops. In total, four guided steps were developed and integrated into the learning material in order to foster students' feedback systems thinking. The learning material for the control group and experimental group consisted of three assignments (see Appendices B and C). The guided steps were integrated into the first two assignments of the learning material for the experimental group. The first two assignments begin with a context describing a control loop in the human body. After each context, four guided steps followed that were only provided to the experimental group. In the third assignment, which is a metacognitive assignment, the students have to construct a general control loop. This assignment is the same for the control group and experimental group.

Guided steps: assignments 1 and 2.

Looking at the learning material, the first two assignments begin with a context which describes two different control loops within the human body, namely the regulation of the thyroid hormones and the regulation of the carbon dioxide level in blood. A fundamental element for assignments 1 and 2 is a visualization of the described control loops by drawing them. According to the article of Chen (2002), the visualization of information aims to provide an insight into an abstract phenomenon by converting abstract information into visual forms. This is important when the contexts describe abstract biological phenomena. In addition, one of the greatest benefits of visualization is that a vast amount of information can quickly be interpreted (Chen, 2002). This is beneficial because the students only have one lesson of forty-five minutes for the assignments.

For assignments 1 and 2, the students from the control group and experimental group are asked to construct a 'scheme' or, in other words, a control loop based on the contexts. Contrary to the control group, the experiment group was guided by the guided steps in the process of identifying and constructing control loops (see Appendix C).

The first guided step focuses on the identification of the components of the described control loop. By letting students focus on the components, they will break down a system into smaller and relatively independent units. This is called a top-down process. Breaking down a system enables students to identify the structure of a system (Burton-Jones & Meso, 2006).

The second guided step focuses on the function of the components. The article by Liu & Hmelo-Silver (2009) showed that students, in their reasoning, remain on a macro-level, rather than diving into the micro-level. Besides this, students have the tendency to focus on observable structures (Hmelo-Silver et al., 2007), while control loops consist of components at micro-levels and macro-levels (e.g. hormones at micro-level and the thyroid gland at macro-level). By letting students focus on the function of the components, the more likely students will focus on micro-level and thus the unobservable components.

For students to be able to construct a control loop, it is important that the relevant components within a control loop and their relationships are identified first (Arndt, 2006). This leads to the third and fourth guided steps. In order to let students identify, represent, and specify the relationships, aspects of causal loop diagrams and concept maps were used for the guided steps. For example, concepts maps focus on the systems' structure and it elucidates the relationships that students perceive between the components (Assaraf and Orion, 2005). Therefore, the third guided step is to draw arrows between the components, which represent their relationships.

The fourth guided step focuses on letting students specify the relationships. The students are made aware of the fact that components can have more than one relationship. This is important because students have a tendency to assume that cause-and-effect relationships are linear and not circular, while control loops are circular (Sweeney & Sternman, 2007). The relationships could be specified by using words, as with concept maps, or by using the symbols + and -, as with causal loop diagrams. By letting students focus on the effects components have on each other, students will be able to identify the feedback loop (specifying the relationship with a minus symbol), which is the negative effect the output of a control loop has on the input.

Metacognitive question: assignment 3.

Assignment 3 is a metacognitive assignment without any guided steps. This assignment is the same for the control group and experimental group. The aim of this assignment is to assess whether students are able to transfer their learning to a new context, which is an assignment in this case. This assignment was based on the four-step modeling process of Loucha and Zacharia (2012), as the students are expected to construct a model ('scheme'). According to Loucha and Zacharia

(2012), the first step towards making a control loop is making systematic observations and/or collecting experiences about the abstract phenomenon. Hence the choice to let the students study their answers to assignments 1 and 2 and write down their observations. The second step is letting students visualize their observations by drawing a general control loop with a feedback mechanism. The last step is letting students come up with an example of a control loop and explain how their general control loop corresponds with their example. The explanation should consist of the components of a general control loop and their functions, the relationships between the components, and the feedback mechanism.

Hypothetical Learning Trajectory

The four guided steps were developed with the aim to foster students' feedback systems thinking. For each guided step the researcher made assumptions about their contribution to the fostering of the feedback systems thinking. In order to assess the assumptions about the effectiveness of the four guidelines (e.g. let students focus on the components), a hypothetical learning trajectory was developed and tested by the researcher (see Table 2).

Table 2. A hypothetical learning trajectory for the developed learning material based on four guidelines.

Teaching activity	**Teacher role**	**Student role**	**Hypothesized learning result**
Introduction	The teacher gives an explanation and instruction on the assignments	The student listens to the teacher's explanation and instructions.	The student knows what is expected of him/her and he/she knows what to do.
Assignment 1: Control loop of the regulation of the thyroid hormones in blood			
Guided step a: Many components play an important role in the regulation of the number of thyroid hormones T3 and T4 in blood. Read the text carefully and write down the main components in the table.	-	The student reads the context about the regulation of the amount thyroid hormones in blood. After finishing reading the context, the student starts reading guided step a. In order to answer the question, the student analyses the context.	The student identifies the components of the control loop by focusing on the relevant components that contribute to the regulation of the thyroid hormones.
Guided step b: Write down the function of each component.	-	After finishing guided step a, the student analyses the context again and writes down the corresponding function for each component.	By focusing on the function of each component the student starts reasoning at micro-and-macro-level instead of only macro-level (e.g. the thyroid hormones at micro-level and the thyroid gland at macro-level).
Guided step c: Use arrows to indicate the relationships between the components.	-	The student analyses the table he/she filled in and tries to figure out how the components are related to each other.	The student can identify the relationships between the components and can indicate it with arrows.
Guided step d: Write down words and symbols at the arrows to specify the relationships. The symbol + for a positive effect and the symbol - for a negative effect of a component on another component.	-	After indicating the relationships between the components, the student focuses on whether components have a stimulating or inhibiting effect on each other. He/she uses words and symbols to specify the relationships.	By specifying the relationships between the components, the student identifies the negative effect the output of a control loop has on the input also referred to as the feedback loop.
Overall result assignment 1: Finishing all the guided steps enables the student to make a control loop of the regulation of the amount thyroid hormones in blood. He/she is able to identify the structure and relationships of the control loop (e.g. the feedback loop).			

Assignment 2: Control loop of the regulation of the carbon dioxide level in blood			
Guided step a: Many components play an important role in the regulation of the level of thyroid hormones T3 and T4 in blood. Read the text carefully and write down the main components in the table.	-	Since the guided steps of assignments 1 and 2 are similar, the student analyses the context on the relevant components involved in the regulation the carbon dioxide level instead of thoroughly reading the whole context.	The student identifies the component of the control loop by focusing on the relevant components that contribute to the regulation of the carbon dioxide level.
Guided step b: Write down the function of each component in the table.	-	After finishing guided step a, the student analyses the context and writes down the corresponding function for each component.	By focusing on the function of each component, the student reasons at micro-level and macro-level (e.g. carbon dioxide at micro-level and the lungs at macro-level).
Guided step c: Use arrows to indicate the relationships between the different components.	-	The student analyses the table he/she just filled in and tries to figure out how the components are related to each other.	The student can identify the relationships between the components and can indicate it with arrows.
Guided step d: To specify the relationships, you will write down words and symbols at the arrows. The symbol + for a positive effect and the symbol - for a negative effect of a component on another component.	-	After indicating the relationships between the components, the student focuses on whether components have a stimulating or inhibiting effect on each other.	By specifying the relationships between the components, the student identifies the feedback loop.
Overall result assignment 2: Finishing all the guided steps enables the student to make a control loop of the regulation of the carbon dioxide level in blood. He/she is able to identify the structure and relationships of the control loop (e.g. the feedback loop).			

Assignment 3: Metacognition of students.			
a: Write down the similarities between the control loops for assignments 1 and 2.	-	The student compares his/her control loops for assignments 1 and 2 and writes down the similarities.	The student identifies the general similarities between the control loops for assignments 1 and 2. While making a comparison the student recognizes the components and relationships within the control loops.
b: Construct a general control loop based on the similarities from assignments 1 and 2.	-	The student reproduces a general control loop based on the similarities he/she wrote earlier.	The student is able to make a general version of control loops, which contains elements such as the receptor, the brain, and the feedback loop.
c: Describe a new situation based on the general control loop.	-	The student studies his/her general control loop and tries to think of an appropriate example and a corresponding explanation.	Based on the general control loop, the student gives a suitable example of a control loop (e.g. the regulation of the male hormones). The student is able to explain his/her example by integrating the components and their functions, the relationships between them into his/her explanation, and the feedback mechanism.

Methods

Research Design

In this study, a design based research was conducted in order to develop learning material to foster the feedback systems thinking. The design of the material was based on four guidelines:

1. Let students focus on the components of a control loop.
2. Let students describe the function of the components.
3. Let students identify the relationships between the components.
4. Let students focus on the presence of a feedback mechanism.

A quasi-experimental research was adopted at one Dutch secondary school in order to determine to what extent the four guidelines fostered the feedback systems thinking. The experimental group received three assignments with four guided steps integrated in the first two assignments; the control group only received the assignments (see Appendices B and C).

Design Process of Learning Material for Intervention

During the designing process, a number of adjustments were made to the design of the learning material in order to increase its effectiveness. The adjustments were made based on two pilot studies and the first intervention round.

Pilot studies.

The first pilot study was an educational conversation between the researcher and a fifth grade student. The researcher verbally provided the student with the guided steps when she had difficulties in answering the assignments. From the first pilot study, it appeared that the guidance of the researcher was effective. The guided steps helped the students in constructing control loops. However, the student needed much guiding to answer the assignments. The researchers' guidance mainly consisted of giving information about the contexts. This showed that the student lacked prior knowledge, which meant that the student mainly focused on reading the contexts instead of identifying the described control loops. Based on this pilot study, two adjustments were made to the learning material. Firstly, the contexts were described in more detail. Secondly, since the intervention would be conducted in a class setting, the teacher's verbal guidance was converted into guided steps on paper.

During the second pilot study, two fifth grade students were instructed to independently answer the assignments of the learning material. Afterward, a semi-structured interview was conducted to get a more in-depth understanding of the students' experiences and their learning. The results of this pilot study were promising. From the students' answers, it was apparent that they were able to identify and understand control loops. During the second pilot study, no adjustments were made to the learning material.

First intervention round.

During the first intervention round, 117 secondary biology students from two urban secondary school in the Netherlands participated. The students were fourth graders (14-15 years old) and fifth graders (16-17 years old). The students were instructed to independently answer the assignments of the learning material. Based on students' answers, the observations by the researcher, and a questionnaire for the experimental group, three adjustments were made to the learning material. Firstly, the contexts were shortened by removing less relevant information (e.g. goiter formation). Secondly, new images were used to support the context. Thirdly, the word ‘model’ was replaced by the word ‘scheme’ for all three assignments. This was adjusted because during the intervention, several students remarked that they did not understand what was expected of them when they were asked to make a model. However, students had a better understanding of the assignments when researcher verbally replaced the word ‘model’ for ‘scheme’. The adjustments resulted in a new and final version of the learning material (see Appendices B and C). This version was used during the second intervention round which lasted 45 minutes. The results from this round were used to answer the research question.

Participants

In total, the number of participants for this study was 37 secondary biology students from one urban secondary school in the Netherlands (see Table 3). The participants for this study were fourth graders (14-15 years old) and fifth graders (16-17 years old) with 18 male and 19 female students. The fourth grade and fifth grade were chosen for the intervention based on the availability of the participating teacher. Both classes were taught by a different teacher. The students did not need to have prior knowledge of the contexts for assignments 1 and 2, which were the regulation of the thyroid hormones and the carbon dioxide level in blood, because the two contexts gave a detailed description of the control loops.

Table 3. The number of participants (control and experimental) and the ratio of male and female students.

Second intervention round	**Control group**			**Experiment group**		
	Grade	**Number of students**	**Male: female**	**Grade**	**Number of students**	**Male: female**
	4	n= 11	5:6	4	n= 12	7:5
	5	n= 5	2:3	5	n= 9	4:5

Data Sources

For this study, three types of materials were used, namely: learning material, observation notes, and a questionnaire. The learning material during the intervention served as a material to provide information about the effectiveness of the guidelines. The observation notes and the questionnaire provided a more in-depth understanding of students' experiences during the intervention. These insights could be used for improving the learning material.

Learning material.

The aim of the learning material was to foster students' feedback systems thinking. The students' answers were used to assess to what extent the guidelines fostered the feedback systems thinking. In order to determine the effectiveness of the guidelines, the control group and the experimental group had different versions of the learning material. Both versions consisted of the first two assignments with the same contexts, namely the regulation of the thyroid hormones and the carbon dioxide level in blood. However, the assignments for the experimental group included the four guided steps based on the four guidelines (e.g. let students focus on the function of the components). An example of a guided step is: "Many components play an important role in the regulation of the amount carbon dioxide in blood. Read the text carefully and write down the main components below in the table." (see Appendix C, p. 43). The control group, on the other hand, received learning material without these guided steps. An example is: "Make a scheme of the control of the carbon dioxide level in blood based on the described process." (see Appendix B, p. 33). Metacognitive assignment 3, which had no guided steps, was the same for both groups. This assignment was used to assess whether students are able to transfer their learning to a new context. The students had forty-five minutes to answer the three assignments.

Observation notes.

Observations served as a tool to gain a more in-depth understanding of students' experiences during the intervention. The observation notes could be used for the improvement of the learning material. For example, if students find the contexts too long then these could be shortened. Students from the control group and the experimental group were observed on aspects such as their behavior and the comments they made. The teachers made notes when a notable aspect occurs more than two times.

Questionnaire.

The questionnaire, like the observation notes, served as a tool to gain a more in-depth understanding of the experience of the students, but only for the experimental group. The results of the questionnaire could also contribute to the improvement of the learning material. After finishing the assignments students were randomly chosen to fill in the questionnaire. The questionnaire consisted of three semi-structured open questions (see Appendix D). The first question focused on what difficulties students experienced while answering the assignments. The second question concerned the effectivity of the guided steps. The third question was whether students think they will recognize a control loop easier and/or faster after making the learning material. The researcher made a division between positive and negative answers of students. For example, when students indicated that the guided steps were not effective, this is considered a negative answer. When two or more students gave a similar answer to the questions then the researcher took the students' answers into account.

Data Analysis

Coding Rubric

The coding rubric used for this study was based on the systemic reasoning rubric of the study of Sweeney and Sternman (2007) who developed and tested it. Similar to the study of Sweeney and Sterman, the focus of this study was not whether the students use the 'right' terms (e.g. control center, effector, and negative feedback) to describe the control loops. Rather, the focus was to determine whether the students were able to identify and understand control loops. To assess students' ability to identify and construct control loops, their answers to assignment 1, 2 and 3 were scored from level x to level four, increasing the level of systemic reasoning. The detailed coding rubric for each assignment is included in the appendix (see Appendix A).

Students' answers were scored as level x when no answer was given. Level 0 meant that the student's answer was 'I don't know', a non-applicable answer was given, or that the answer was incorrect. An example of non-applicable answers is a summary of the contexts for assignments 1 and 2 instead of a model of the control loops. An answer was incorrect when the student had identified zero correct components (e.g. receptor and brain). Answers were scored as level 1 if they showed elementary awareness, which means the student recognized more than one components of a control loop and were able to construct a linear control loop. This means that the students were able to identify the relationships between the components, but not able to identify the feedback loop which made the control loops circular. Students' answers were scored as level 2 if they recognized that the control loop was circular, but the student did not identify the inhibiting effect of the output on the input of a control loop (the feedback loop). Answers were scored level 3 when students demonstrated awareness of systems' behaviors and characteristics. This means that the students were able to identify the circularity of a control loop and the feedback loop.

However, the student did not identify all the correct components of the control loop. The last and highest level was level 4. Students' answers were scored as level 4 when the student was able to identify all the components, the correct relationships between the components, the circularity of a control loop, and the feedback loop.

Important to note is that for assignments 1 and 2 of the experimental group, only the student's final products, which were the control loops, were coded. The guided steps were developed to foster the feedback systems thinking, which means identification and understanding of control loops. Therefore, only scoring the control loops gives insights into the effectiveness of the guidelines.

Interrater Reliability

In order to determine the reliability of the coding, the interrater reliability was determined for each assignment. The students' answers for assignments 1, 2, and 3 were coded by the researcher. That is in total 15 students from the control groups and 19 students from the experimental group. A second rater coded the answers of 10% of the students from the control group and 12% of the students from the experimental group. The Cohen's Kappa for each assignment is above 0.77 (see Table 4). With $0.61 \leq \kappa \geq 0.80$ as substantial and $0.81 \leq \kappa \geq 1.00$ as almost perfect, the interrater reliability for this study is substantial to good (McHugh, 2012). This indicates that the coding conducted by the researcher was reliable.

Table 4. The Cohen's kappa for assignments 1, 2, and 3.

Assignment	**Cohen's Kappa**
1	0.96
2	0.90
3a	0.81
3b	0.77
3c	0.93

Results

Answers from students from the control group and experimental group were scored and processed. Table 5 is a representation of the number of students that scored levels 0 to 4 for assignments 1, 2, and 3. To determine to what extent the guided steps were effective in fostering students' feedback systems thinking, the focus was on the three skills of feedback systems thinking: identifying the structure, identifying the relationships, and understanding the feedback mechanism.

Table 5. The number of students from both conditions (control and experimental) that scored level 0 to level 4 for assignments 1, 2, and 3 (A1 – A3c) during the intervention. The experimental group was provided with guided steps for assignments 1 and 2 to identify and construct control loops whereas the control group did not have any guidance.

Level	**Control group n=16**					**Experimental group n=21**				
	A1	A2	A3a	A3b	A3c	A1	A2	A3a	A3b	A3c
x	1	1	1	3	4	3	7	7	12	15
0	2	5	9	6	3	6	1	11	4	4
1	7	8	6	2	3	7	8	3	2	2
2	4	2	0	1	4	3	3	0	1	1
3	2	0	0	1	0	2	2	0	2	0
4	0	0	0	0	0	0	0	0	0	0

Note:. Level x = student did not give an answer; level 0 = non-applicable/incorrect answer; level 1 = identification of a linear control loop with correct relationships, but lacks circularity; level 2 = identification of a circular control loop consisting of partially correct components, but lacks the feedback loop; level 3 = identification of a circular control loop consisting of partially correct components and the feedback loop; level 4= identification of a completely correct control loop (all the correct components and relationships, the circularity and the feedback loop).

The Extent of Fostering Feedback Systems Thinking: Assignments 1 and 2

For assignments 1 and 2 where the students had to construct a control loop based on the given contexts (e.g. regulation of the thyroid hormones) the focus was on skills 1 and 2, respectively the ability to identify the structure of a control loop and the ability to identify relationships within a control loop. Despite that none of the students were able to construct completely correct control loops (see Table 5 – level 4), they were able to identify and construct partially correct control loops. For example, students were able to identify control loops with the correct components and with the correct relationships of a control loop.

Skill 1: identifying the structures.

For skill 1, the focus was on the number of students that were able to correctly identify the components of the control loops. For assignments 1 and 2, where only the experimental group was guided in constructing control loops, the experimental group performed better in identifying all the components of the control loops. Two students from the experimental group were able to identify all the components, whereas only one student from the control group was able to do the same (see Figure 4 and Appendix E – Table 6). Figure 2 shows the control loop of a student from the experimental group for assignment 1. This example shows that the student was able to identify all the correct components (the brain parts, receptor, thyroid, and the thyroid hormones) and in other words the structure of the control loops.

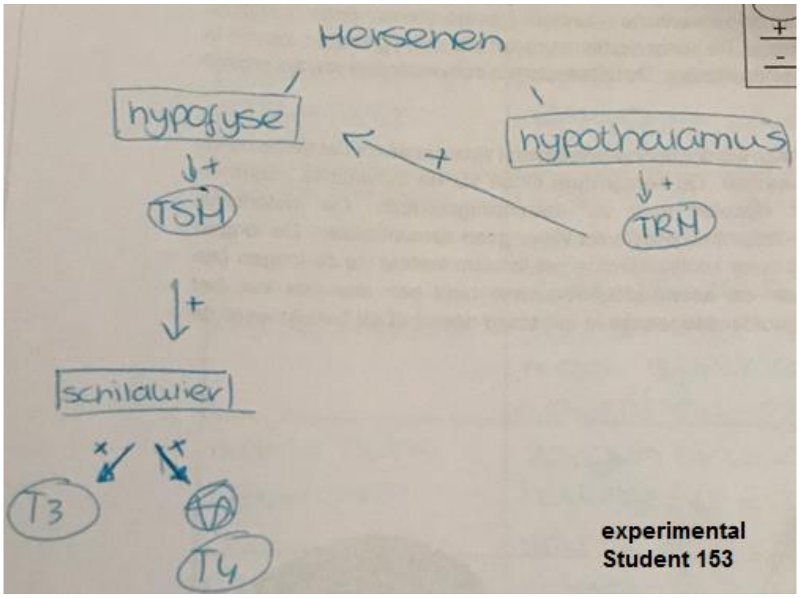

Figure 2. An example of the control loop constructed by student 153 (experimental group) for assignment 1. The student was able to identify all the correct components of the control loop regulating the level of thyroid hormones in blood, namely: brain parts, the thyroid gland and hormones, and the receptor.

Skill 2: identifying the relationships.

For skill 2, the focus was on students being able to identify the relationships between the components. This means the correct relationships between the components, the circularity of control loops, and the presence of a feedback loop. For assignments 1 and 2, the experimental group performed better than the control group in identifying the correct relationships between the components of the control loops. Four students from the experimental group were able to construct circular control loops with the correct relationships and the feedback loop (the relationship specified with '-'), whereas two students from the control group were able to do the same (see Figure 4). Figure 3 shows that a student from the experimental group that was able to identify the feedback loop (see Figure 3 – right), whereas the student from the control loop was not able to identify the feedback loop (see Figure 3 – left).

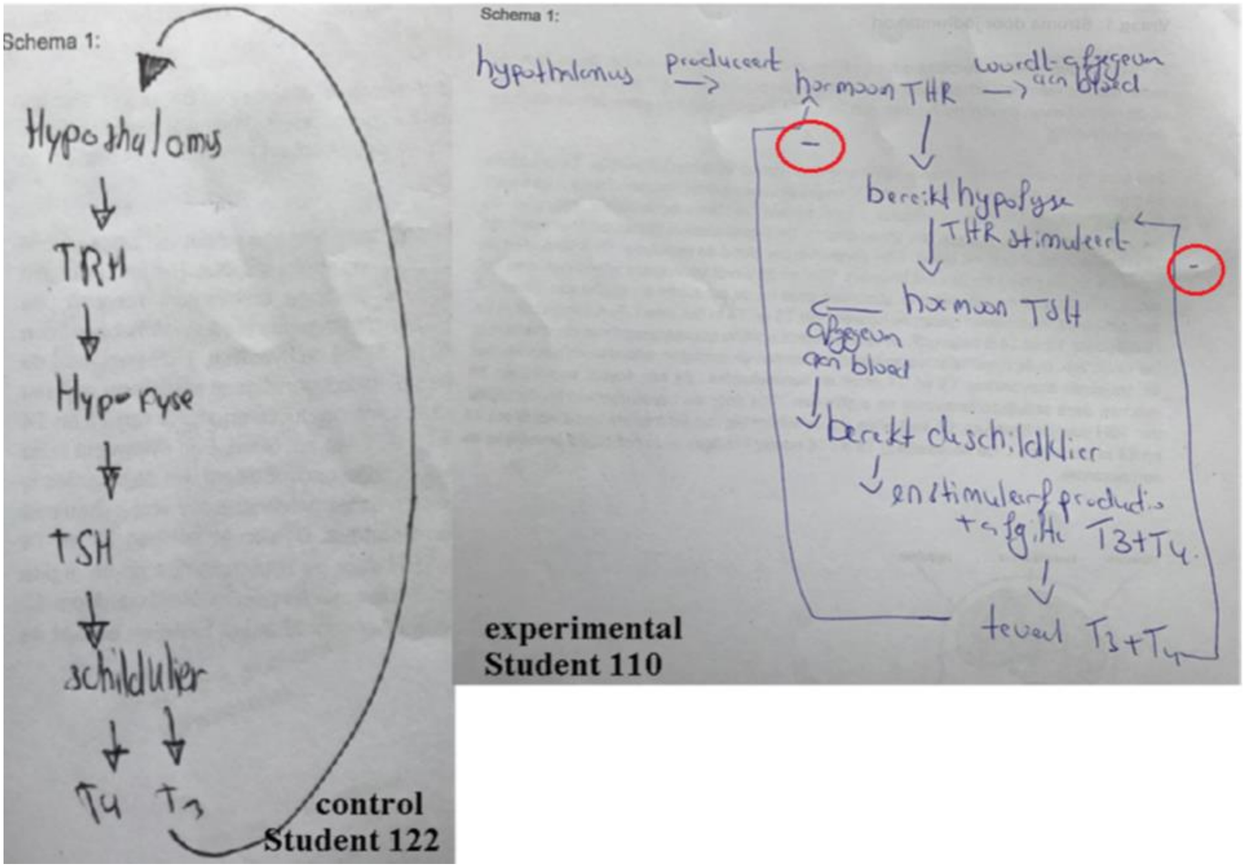

Figure 3. Left: An example of the control loop by student 122 (control group) for assignment 1. The student identified the correct relationships and the circularity of the control loop. However, the student did not specify the relationships which led to identifying the feedback loop. Right: An example of the control loop constructed by student 110 (experimental group) for assignment 1. The student identified the correct relationships, the circularity, and the feedback loop (red circles).

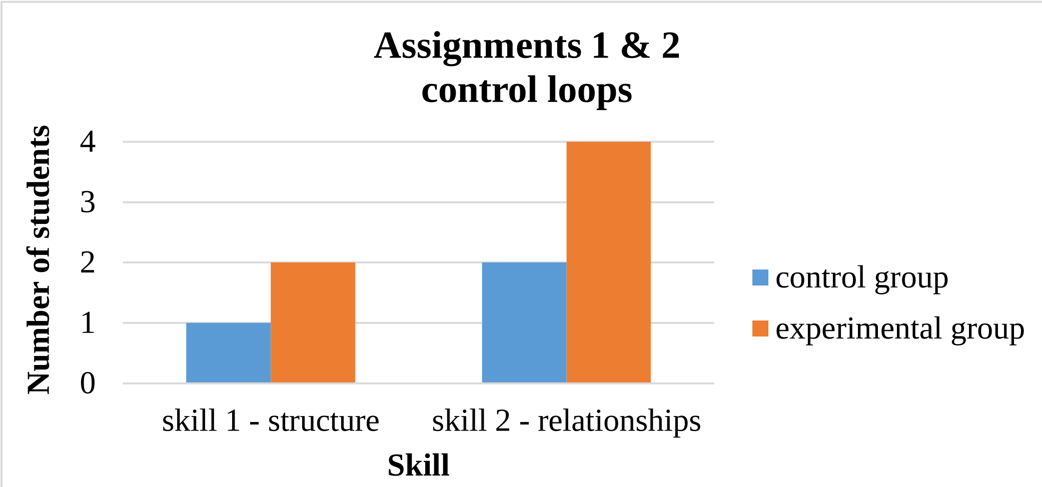

Figure 4. A bar graph for assignments 1 and 2 (with or without the guided steps) with the number of students (y-axis) who achieved skills 1 and 2 (x-axis) for identifying control loops which regulate of the thyroid hormones (assignment 1) and the carbon dioxide level in blood (assignment 2).

Metacognitive Assignment 3

For students to be able to construct a general control loop they first had to write down the general similarities between the control loops for assignments 1 and 2 in assignment 3a. For assignment 3b, the students had to construct a general control loop based on the similarities, the focus was also on skills 1 and 2 (identifying the structure and the relationships). These two skills concern the identification of a general control loop. Despite that none of the students were able to construct completely correct control loops (see Table 5 – level 4) they were able to identify and construct partially correct control loops (see skill 1 and 2).

For assignment 3c, the students had to give an own example of a control loop (e.g. temperature regulation) and a corresponding explanation which supported their example. The explanation should consist of the components of the control loop and their functions, and the relationships between the components. The focus of this assignment was on skill 3, which is understanding of the feedback mechanism. For this assignment, there was no guidance by the guided steps for the experimental group or the control group.

Skill 1: identifying the structure.

For skill 1, the focus was on the number of students identifying the components of a general control loop. For assignment 3b, the experimental group performed better than the control group in identifying the components of a general control loop (see Figure 6 and Appendix E – Table 6). One student from the experimental group was able to identify all the four components of a general control loop (see Figure 5 – above) whereas none of the students from the control group were able to identify all the components (see Figure 5 - below). Six students from the control group were able to identify three of the four components of the general control loop (see Figure 5 – below).

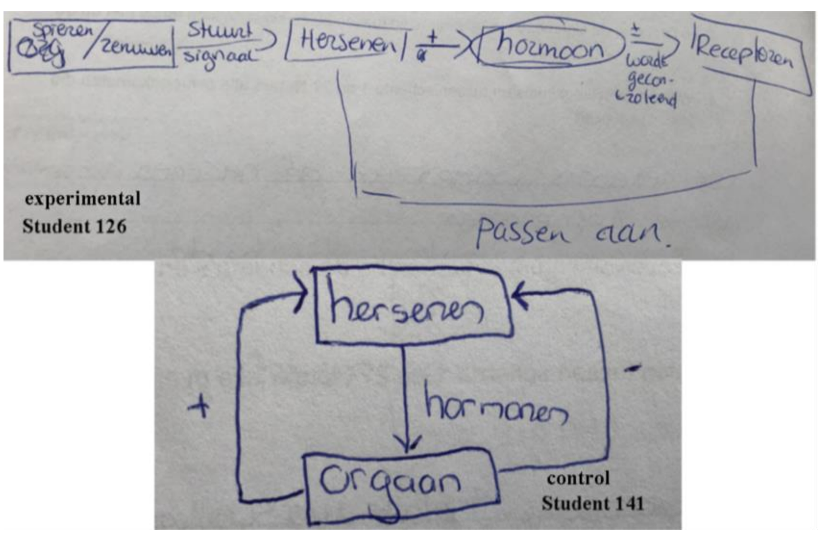

Figure 5. Above: An example of the control loop by student 126 (experimental group) for metacognitive assignment 3. The student identified all four correct components of a general control loop, namely: organs, brain, hormones, and receptors. Below: An example of the control loop constructed by student 141 (control group) for metacognitive assignment 3. The student identified three components of a general control loop, namely: organs, brain, and hormones.

Skill 2: identifying the relationships.

For skill 2 the focus was on students being able to identify the relationships between the components. Which means the correct relationships between the components, the circularity of control loops, and the feedback loop. For assignment 3b, the experimental group performed better than the control group in identifying the correct relationships between the components. Two students from the experimental group were able to construct a general control loop with all the correct relationships, the circularity, and the feedback loop (the relationship specified with '-'), whereas one student from the control group was able to do the same (see Figure 6).

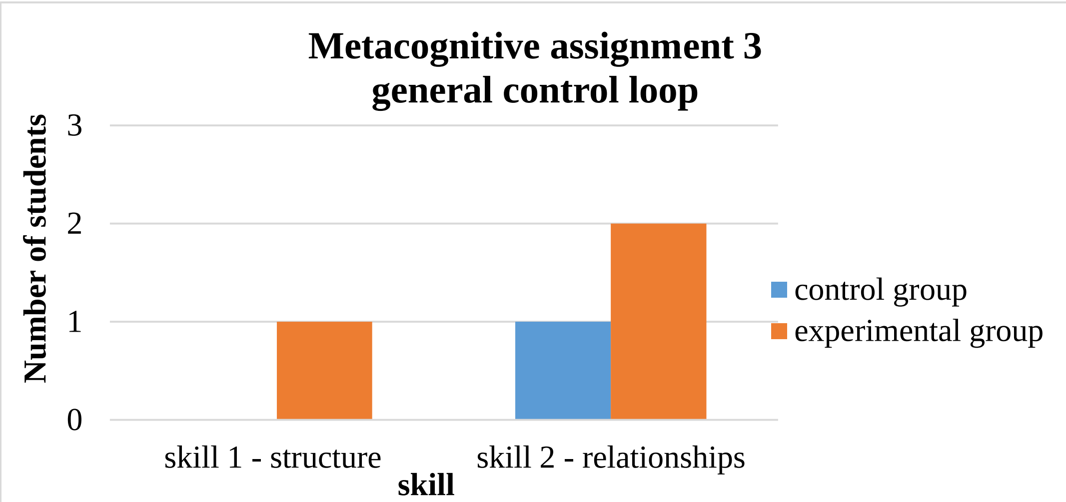

Figure 6. A bar graph for assignments 3 (without guided steps) with the number of students (y-axis) who have achieved skills 1 and 2 (x-axis) for constructing a general control loop.

Skill 3: understanding the feedback mechanism.

For assignment 3c, the students had to give an example of a control loop and support their example. This shows that for assignment 3c the focus was on skill 3, which is the ability to understand control loops. For this assignment the control group performed better than the experimental group in understanding the feedback mechanism. Four students from the control group were able to give a correct example of a control loop with a partially correct explanation (see Table 5 – level 2). For example, a student from the control group gave the example of the hormonal regulation of the menstrual cycle (see student 121). The explanation consisted of two components (hormones and the brain), their function, and the relationships between the components. Whereas only one student from the experimental group was able to reach the same level.

Student 121: *“Hormonal regulation of the menstrual cycle. Hormones play an important role and they have both positive and negative effects. The hormones go through the brain to the blood and have a norm value.”*

Students’ Experiences during the Intervention

Observations notes.

During the intervention, a number of relevant observation points emerged. Firstly, it soon became apparent that students had difficulties with reading and understanding the contexts. Students indicated that the contexts were too long and difficult for them. For example, students pointed out that they did not understand what was meant by the words T3 and T4. Secondly, it appeared that wording of the assignments was not clear enough for the students. For example, multiple students indicated that they did not understand what was expected of them for assignment 3. Thirdly, particular students from the experimental group lacked sufficient time to answer all the assignments. This resulted in more than the half of all students not answering assignment 3 (see Table 5 – level x).

Questionnaire.

From the questionnaire, it appeared that the students experienced the contexts as difficult to read and to understand. In addition, the students indicated that they experienced the contexts as long and confusing (see student 104 and 148).

Student 104: "*The long text was confusing and therefore it is difficult to extract information from the text as good as possible*."

Student 148: *"Yes, I found the texts difficult and long. I found some questions unclear."*

The number of unfamiliar concepts (e.g. the thyroid hormones T3 and T4) made the contexts difficult to understand for the students. This, combined with the length of the text, made it challenging for them to extract relevant information from the contexts.

Opinions were divided about the effectiveness of the guided steps. Some students found that the guided steps were effective because they guided them through the process of constructing the control loops for assignments 1 and 2 (see student 148). Other students, however, felt that the assignments were not easier to understand because of the guidance (see student 147).

Student 148: *"Yes, they have helped."*

Student 147: *"No."*

Finally, for the final question, students' answers were diverse. Some students indicated that they would be able to identify control loops faster and/or easier in the future (see student 150), whereas other doubted that they would be able to or indicated that they could not identify control loops at all (see student 151).

Student 150: *"Yes, now we've covered it in class."*

Student 151: *"Probably"*

Conclusion

The aim of this study was to determine guidelines for learning material that foster students' feedback systems thinking, from which followed the research question: What are guidelines for learning material that foster students' feedback systems thinking in secondary school biology education? Based on the main characteristics of control loops (structure, relationships, and self-regulation), the following four guidelines were formulated:

1. Let students focus on the components of a control loop.
2. Let students describe the function of the components.
3. Let students identify the relationships between the components.
4. Let students focus on the presence of a feedback mechanism.

These guidelines were converted into four guided steps and integrated into the first two assignments of learning material in order to foster students' feedback systems thinking. The students' answers were used to assess to what extent the guidelines fostered the feedback systems thinking. The results indicate that the four guidelines are potentially successful in fostering skill 1 (identification of the structure) and skill 2 (identification of the relationships). Considering skill 1, the experimental group performed better in identifying all the components of the control loops for all the three assignments. As for skill 2, the experimental group performed better in identifying the correct relationships between the components for all three the assignments. Which means students identified the correct relationships between the components, the circularity of the control loops, and the present feedback loops. In regards to skill 3, the results showed that the control group performed better than the experimental group in understanding the feedback mechanism. Only one student from the experimental group was able to give a correct example of a control loop (e.g. the regulation of the body temperature) and explain the feedback mechanism that enables the control loop to regulate itself.

Overall, the four guidelines as a whole is potentially successful in fostering students' feedback systems thinking to a certain extent, as they are able to foster students' identification of control loops. The guidelines are unsuccessful in fostering students' understanding of control loops.

Discussion

Although this study was carefully prepared, the limitations and the shortcomings of this study are acknowledged. Firstly, what turned out to be evident from the results of second intervention round was that the level of the contexts was too high for the students, despite the adjustments in learning material for the second intervention (e.g. removing less relevant information from the context). From the students' comments in the observations notes and questionnaires, it appeared that the described contexts were new to them. The teachers had not yet discussed the regulation of the thyroid hormones and regulation the carbon dioxide level in blood with the students. This led to words such as T3 and T4 being confusing and difficult to understand for the students. In addition, students trying to understand contexts that consisted of a number of unfamiliar words and definitions diverted their attention from identifying and understanding the described control loops in the contexts. Furthermore, because students mainly focused on trying to read and understand the contexts, they did not have the time to answer all the assignments. The students' experiences and their lack of answers for the assignments highlight the importance of prior knowledge. For this study, students did not require to have prior knowledge of the contexts. For students to be able to identify and understand control loops and being able to answer all the assignments, the prior knowledge of the students should be taken into account. This could be achieved by adjusting the contexts for assignments 1 and 2 to subjects the biology teachers already covered in class. This means that the guidelines for learning material should not only focus on the characteristics of a control loop, but also on students' prior knowledge.

Secondly, this study shows that the four guidelines for learning material are potentially successful in fostering students' ability to identify control loops. However, the guidelines are not successful in fostering students' ability to understand control loops. From the results, it appeared that the control group performed better than the experimental group in understanding the feedback mechanism, whereas the expectation was that the experimental group would perform better. This means that in regard to the guidelines, there should be more focus on the understanding of control loops. For example, Liu & Hmelo-Silver (2009) developed 'function-centered' conceptual representation with the emphasis on the function and behavior of systems. From their study, it appeared that the conceptual representation resulted in students developing a deeper understanding of complex systems. Thus by letting students first focus on the function of a system, they developed a deeper understanding of systems. For this study, the students did focus on function, but only on the function of the components and not of the whole control loop. Therefore, in future assignments, the students should not only focus on the function of the components, but also on the function of the whole control loop. This could be achieved by letting students formulate the function of the control loop based on the components' function after they completed constructing the control loop.

Further Research

This study focused on guidelines for learning material that fosters students' feedback systems thinking. Continued efforts are needed to make the guidelines more accessible for biology teachers. For further research on fostering students' feedback systems thinking, the biology teachers should be included in the learning process of the students, whereas in the current study the teacher was limited to handing out the learning material and maintaining order during the intervention. Since teachers play an important role in students' learning, it would be more effective to move the focus from written guided steps to teachers' guidance. This to eventually supply teachers with tools they can easily use and integrate multiple times during their lessons throughout the year to foster students' feedback systems thinking without it being very time-consuming.

Acknowledgment

The comments, suggestions, and insights of Dr. M.C.P.J. (Marie-Christine) Knippels and M.G.R. (Melde) Gilissen, MSc during this study and on the concept versions of this thesis are gratefully acknowledged. In addition, the contribution of Remco van Eck in coding students' answers is also appreciated.

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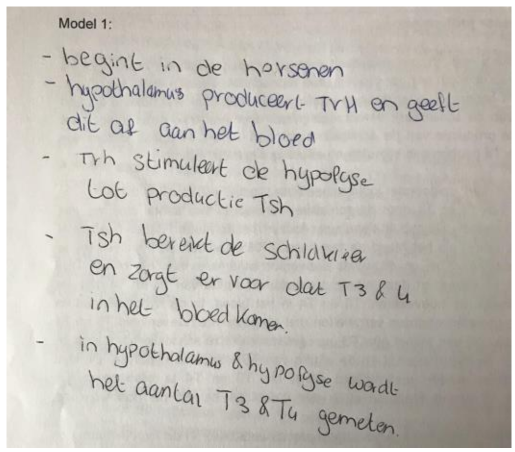
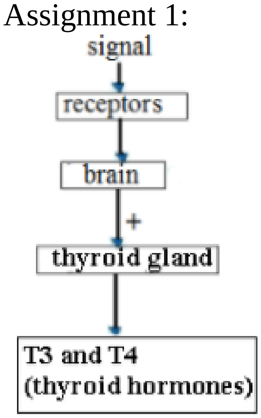
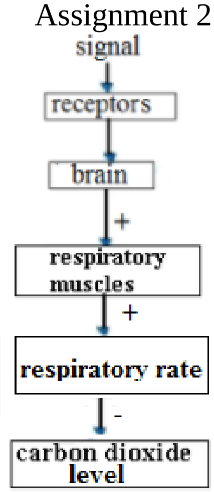
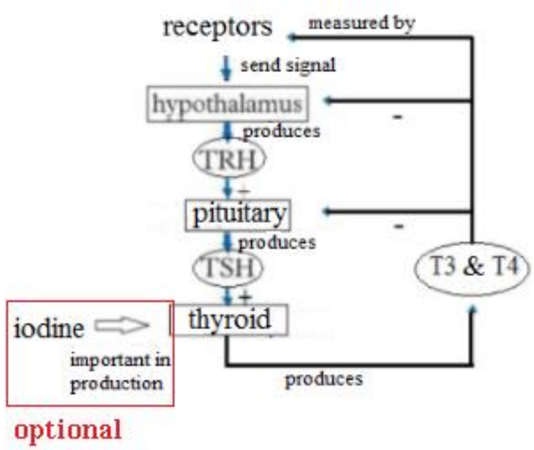
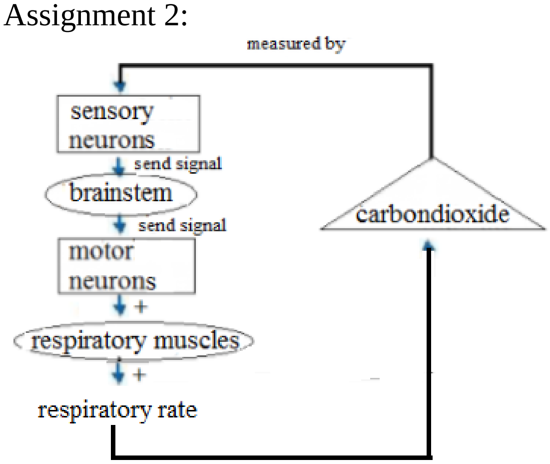
Appendix A

Coding rubric for students' answers to the worksheet

Assignments 1 & 2

Level	**Description**	**Example**
x	No answer is given	The student has written nothing.
0	Incorrect and non-applicable answer: - students' answer is not a model the whole model of a control loop is incorrect	- The student has written 'I do not know.' - The student made a summary of the text, which mainly consists of words. He/she did not make a control loop. 
1	Elementary awareness: - partially correct components of a control loop - linear cause-and-effects relationships - wrong or missing feedback mechanism - no circular control loop	Assignment 1:  Assignment 2: 

2	Seeing control loops: - partially correct components of a control loop - the circular control loop - wrong or missing feedback mechanism	
3	Seeing control loops: - partially correct components of a control loop - circular cause-and-effect relationships - the correct feedback mechanism	See level 3!
4	Understanding loops with feedback mechanism: - all correct components of a control loop -circular cause-and-effect relationships - the correct feedback mechanism	Assignment 1:  Assignment 2: 

Assignment 3a

Level	Description	Example
x	No answer is given	The student has written nothing.
0	Incorrect and non-applicable answer: - all similarities are incorrect - non relevant similarities	- The student has written 'I do not know.' - There are organs in both models. 'Blood transports both (hormones and carbon dioxide).' 'The processes both have to do with your health.'
1	Elementary awareness: - less than three correct similarities	- the amount of a substance in blood is measured by receptors - the receptors send a signal consisting of the measured value to the brain - the brain compares the measured value with the norm value - the brain stimulates an organ, this leads to an effect (increase or decrease of the amount of substance) - It is a control loop/cycle. - negative feedback - absence cause-and-effect relationships
2	Seeing control loops: - three (or more) correct and relevant similarities	- the amount of a substance in blood is measured by receptors - the receptors send a signal consisting of the measured value to the brain - the brain compares the measured value with the norm value - the brain stimulates an organ, this leads to an effect (increase or decrease of the amount of substance) - It is a control loop/cycle. - negative feedback - absence cause-and-effect relationships

Assignment 3b

Level	Description	Example
x	No answer is given	The student has written nothing
0	Incorrect and non-applicable answer: - students' answer is not a model the whole model of a control loop is incorrect	- The student has written 'I do not know.'

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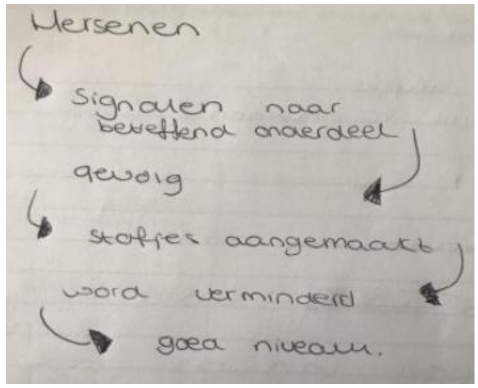
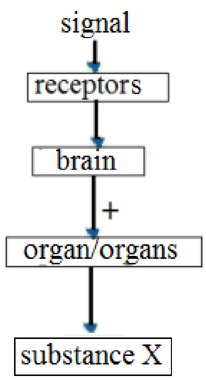
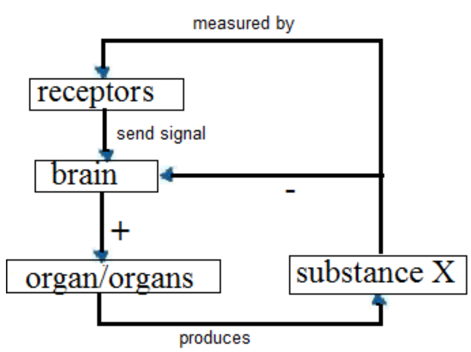
<tr><td></td><td></td><td>
</td></tr>
<tr><td>1</td><td>Elementary awareness:
- partially correct components of a control loop
- linear cause-and-effects relationships
- wrong or missing feedback mechanism
→ no circular control loop</td><td>
</td></tr>
<tr><td>2</td><td>Seeing control loops:
- partially correct components of a control loop
- the circular control loop
- wrong or missing feedback mechanism</td><td></td></tr>
<tr><td>3</td><td>Seeing control loops:
- partially correct components of a control loop
- circular cause-and-effect relationships
- the correct feedback mechanism</td><td>
</td></tr>
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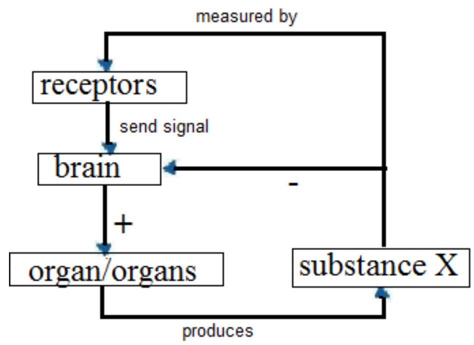
<table>
<tr>
<td>4</td>
<td>Understanding loops with feedback mechanism:
- all correct components of a control loop
-circular cause-and-effect relationships
- the correct feedback mechanism</td>
<td>
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</table>

Assignment 3c

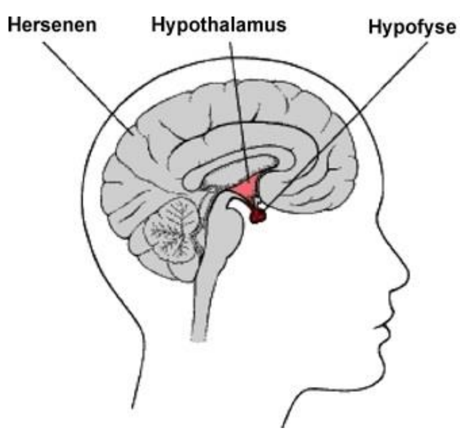
Level	**Description**	**Example**
x	No answer is given	The student has written nothing
0	Incorrect and non-applicable answer: - wrong example + wrong explanation	-The student has written 'I do not know.' - 'The digestion, because it must be reduced.' 'The regulation of the amount of saliva.'
1	Elementary awareness: - correct example + wrong or missing explanation - wrong or missing example + partially correct explanation	- 'The increase of TSH and LH and also the decrease of it. FSH and LH both have a different effect there. - 'Receptors indicate the value to the brain, which therefore gives a signal to organs to make hormones. The hormones stimulate other organs to work harder. '
2	Advanced awareness: - correct example + partially correct explanation - wrong or missing example + complete correct explanation	
3	Successful integrative thinking + full understanding control loop principle: - correct example + complete correct explanation	'The cycle of a man. The process starts in the pituitary gland. The pituitary gland delivers hormones to the blood. Those hormones arrive in the hormone-producing organ (testes). The testes are stimulated to make testosterone. Testosterone has a stimulating effect on the production of sperm cells. But too much testosterone has a negative effect on the pituitary gland. And that's how everything stays in balance.'

Appendix B
Worksheet control group second intervention round

Vraag 1: Struma door jodiumtekort

In 1942 werden bakkers verplicht om gejodeerd zout toe te voegen aan het brood. Met als reden dat het menselijk lichaam zelf geen jodium kan produceren. Jodium is zeer belangrijk bij de productie van de schildklierhormonen T3 en T4, deze hebben een stimulerend effect op de stofwisseling.

Een gezond persoon met voldoende jodium heeft een goed werkende schildklier. De productie en afgifte van de T3 en T4 door de schildklier verloopt in een aantal stappen. Het proces begint in de hersenen. Dit orgaan bestaat onder andere uit twee onderdelen, namelijk: de hypothalamus en de hypofyse (zie afbeelding 1). De hypothalamus produceert het hormoon TRH en geeft dit af aan het bloed. TRH bereikt via het bloed de hypofyse. TRH stimuleert de hypofyse tot de productie van het hormoon TSH en dit wordt vervolgens afgegeven aan het bloed. TSH bereikt de schildklier en stimuleert deze tot de productie en afgifte van T3 en T4 aan het bloed. Receptoren meten de hoeveelheid T3 en T4 in het bloed. Een evenwicht in de hoeveelheid T3 en T4 is belangrijk en daarom wordt continu gecontroleerd wat de waardes in het bloed zijn. In de hypothalamus en hypofyse worden de gemeten waardes vergeleken met de gewenste hoeveelheid T3 en T4 ofwel de normwaardes. Bij een teveel aan T3 en T4 remmen deze schildklierhormonen de afgifte van TRH door de hypothalamus en de afgifte van TSH door de hypofyse. Dit leidt ertoe dat de schildklier minder gestimuleerd wordt om T3 en T4 te produceren. De hoeveelheid T3 en T4 neemt hierdoor af in het bloed en bereikt de normwaardes.



Afbeelding 1. De hersenen met als onderdelen de hypothalamus en de met hypofyse.

Vraag: Zet het beschreven proces (de regeling van de hoeveelheid T3 en T4) in de tekst om tot een schema .

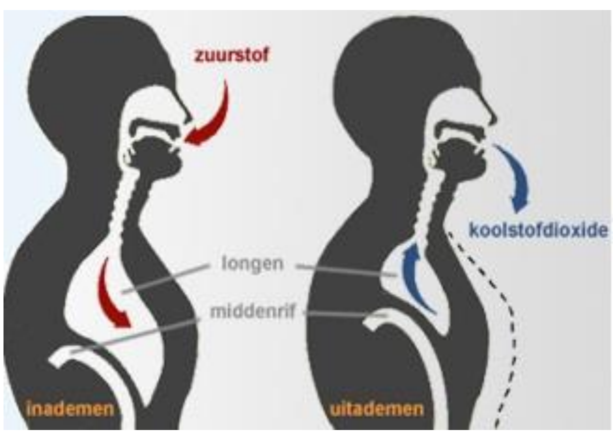
Schema 1:

Vraag 2: Hardlopen & ademhaling

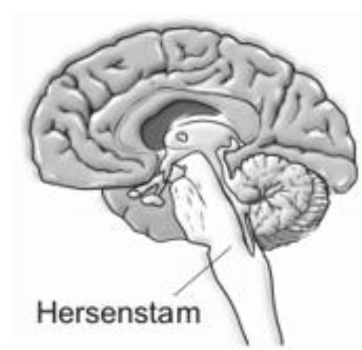
In Nederland is hardlopen een onderdeel van gymles op de middelbare scholen. Na het hardlopen, zijn veel leerlingen buiten adem. Het blijkt dat bij de leerlingen het koolstofdioxidegehalte is toegenomen in het bloed door verbranding van suikers. Als gevolg van de toename van het koolstofdioxidegehalte gaan de leerlingen sneller ademhalen. Dit betekent dat de ademhalingsfrequentie toeneemt van 20 keer per minuut (normale ademhaling) naar 80 keer per minuut.

Een evenwicht in het koolstofdioxidegehalte is belangrijk en daarom wordt continu gecontroleerd wat de waardes in het bloed zijn. Het koolstofdioxidegehalte in het bloed wordt gemeten door de receptoren van de sensorische neuronen (gevoelszenuwcellen). Neuronen zijn onderdeel van het zenuwstelsel. De sensorische neuronen sturen de gemeten waarde in de vorm van een signaal naar de hersenstam. De hersenstam is een onderdeel van het orgaan de hersenen (zie afbeelding 3).

Bij een hoog koolstofdioxidegehalte wordt door de hersenstam waargenomen dat de gemeten waarde hoger is dan de normwaarde. De hersenstam stuurt via de motorische neuronen (bewegingszenuwcellen) meer signalen naar de ademhalingsspieren. De motorische neuronen zorgen ervoor dat de ademhalingsspieren vaker gaan samentrekken. De longen zetten vaker uit, dit houdt in dat meer koolstofdioxide het lichaam verlaat via de longen (zie afbeelding 2). Een toename van de ademhalingsfrequentie remt een toename van het koolstofdioxidegehalte. Het koolstofdioxidegehalte in het bloed neemt af en bereikt weer de normwaarde.



Afbeelding 2. Een weergave van de ademhaling.



Afbeelding 3. De hersenen (orgaan) met als onderdeel de hersenstam.

Vraag: Zet het beschreven proces (de regeling van het koolstofdioxidegehalte) in de tekst om tot een schema .

Schema 2:

Vraag 3: Zoek de overeenkomsten

Je hebt de eerste twee vragen gelezen en beantwoord. Ondanks dat er twee verschillende situaties beschreven zijn en deze op het eerste gezicht niet op elkaar lijken, zijn er wel degelijk overeenkomsten. Deze overeenkomsten bevinden zich bij de onderliggende processen van beide situaties. Om de onderliggende processen te vergelijken, kun je gebruik maken van de zelfgemaakte schema's 1 en 2.

Kijk vooral naar de algemene overeenkomsten tussen beide schema's en focus niet op de details.

a. Wat zijn de overeenkomsten tussen schema 1 en 2? Noteer alle overeenkomsten die je kunt bedenken.

b. Maak op basis van de overeenkomsten bij vraag a een algemeen schema. Dit schema moet dus van toepassing zijn op beide voorbeelden.

Bij het maken van een schema kun je gebruik maken van:
- hokjes: om daarin tekst te noteren
- pijlen: om relaties weergeven
- symbolen (+ en -) en woorden: om relaties te beschrijven

c. Tenslotte, bedenk nu bij het schema van vraag b een passend voorbeeld, zoals die bij vraag 1 en 2. Leg jouw voorbeeld uit.

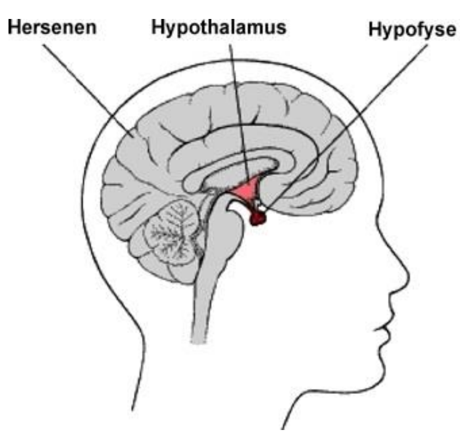
Appendix C

Worksheet experimental group second intervention round

Vraag 1: Struma door jodiumtekort

In 1942 werden bakkers verplicht om gejodeerd zout toe te voegen aan het brood. Met als reden dat het menselijk lichaam zelf geen jodium kan produceren. Jodium is zeer belangrijk bij de productie van de schildklierhormonen T3 en T4, deze hebben een stimulerend effect op de stofwisseling.

Een gezond persoon met voldoende jodium heeft een goed werkende schildklier. De productie en afgifte van de T3 en T4 door de schildklier verloopt in een aantal stappen. Het proces begint in de hersenen. Dit orgaan bestaat onder andere uit twee onderdelen, namelijk: de hypothalamus en de hypofyse (zie afbeelding 1). De hypothalamus produceert het hormoon TRH en geeft dit af aan het bloed. TRH bereikt via het bloed de hypofyse. TRH stimuleert de hypofyse tot de productie van het hormoon TSH en dit wordt vervolgens afgegeven aan het bloed. TSH bereikt de schildklier en stimuleert deze tot de productie en afgifte van T3 en T4 aan het bloed. Receptoren meten de hoeveelheid T3 en T4 in het bloed. Een evenwicht in de hoeveelheid T3 en T4 is belangrijk en daarom wordt continu gecontroleerd wat de waardes in het bloed zijn. In de hypothalamus en hypofyse worden de gemeten waardes vergeleken met de gewenste hoeveelheid T3 en T4 ofwel de normwaardes. Bij een teveel aan T3 en T4 remmen deze schildklierhormonen de afgifte van TRH door de hypothalamus en de afgifte van TSH door de hypofyse. Dit leidt ertoe dat de schildklier minder gestimuleerd wordt om T3 en T4 te produceren. De hoeveelheid T3 en T4 neemt hierdoor af in het bloed en bereikt de normwaardes.



Afbeelding 1. De hersenen met als onderdelen de hypothalamus en de met hypofyse.

Bij de regeling van de hoeveelheid schildklierhormonen T3 en T4 in het bloed spelen verschillende onderdelen een belangrijke rol. Lees de tekst goed door en noteer de belangrijkste onderdelen hieronder in de tabel.

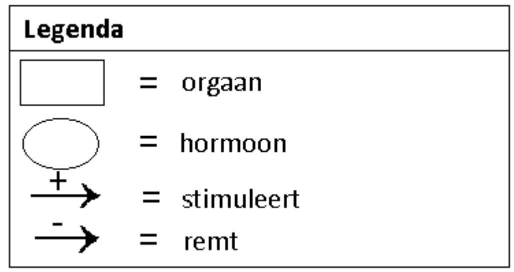
a. Noteer nu bij a achter ieder onderdeel wat de functie is.

Onderdelen	**Functie**

b. Probeer hieronder met behulp van pijlen aan te geven wat de relaties zijn tussen de verschillende onderdelen, die je bij a hebt genoteerd. Een voorbeeld van een relatie is: onderdeel A heeft invloed op onderdeel B (A → B).

Houdt er rekening mee dat een onderdeel relaties kan hebben met meerdere onderdelen.

Schema 1:



d. Bij vraag c heb je de relaties tussen onderdelen weergegeven met pijlen. Om de relaties meer te schematiseren, ga je gebruik maken van symbolen (+ en -) en woorden. Deze noteer je bij de getekende pijlen.

Om aan te geven dat een pijl een stimulerend effect heeft, zet je een + neer bij de pijl. Om aan te geven dat een pijl een negatief effect heeft, zet je een – neer bij de pijl.

Vraag 2: Hardlopen & ademhaling

In Nederland is hardlopen een onderdeel van gymles op de middelbare scholen. Na het hardlopen, zijn veel leerlingen buiten adem. Het blijkt dat bij de leerlingen het koolstofdioxidegehalte is toegenomen in het bloed door verbranding van suikers. Als gevolg van de toename van het koolstofdioxidegehalte gaan de leerlingen sneller ademhalen. Dit betekent dat de ademhalingsfrequentie toeneemt van 20 keer per minuut (normale ademhaling) naar 80 keer per minuut.

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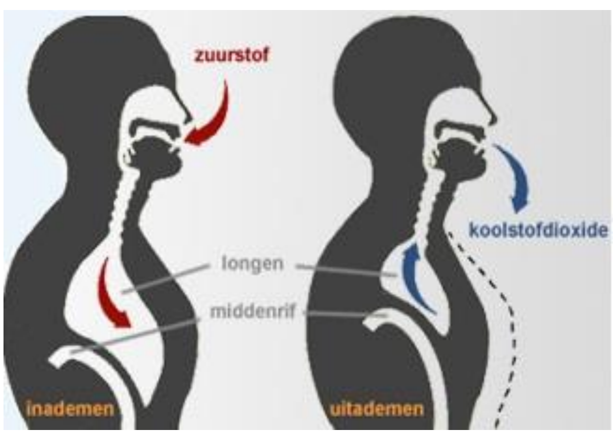
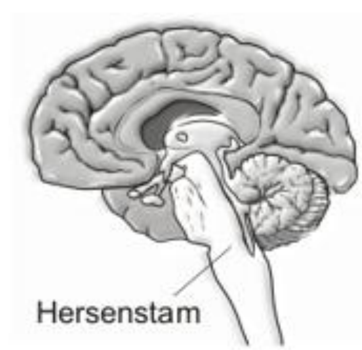
Bij een hoog koolstofdioxidegehalte wordt door de hersenstam waargenomen dat de gemeten waarde hoger is dan de normwaarde. De hersenstam stuurt via de motorische neuronen (bewegingszenuwcellen) meer signalen naar de ademhalingsspieren. De motorische neuronen zorgen ervoor dat de ademhalingsspieren vaker gaan samentrekken. De longen zetten vaker uit, dit houdt in dat meer koolstofdioxide het lichaam verlaat via de longen (zie afbeelding 2). Een toename van de ademhalingsfrequentie remt een toename van het koolstofdioxidegehalte. Het koolstofdioxidegehalte in het bloed neemt af en bereikt weer de normwaarde.



Afbeelding 2. Een weergave van de ademhaling.



Afbeelding 3. De hersenen (orgaan) met als onderdeel de hersenstam.

a. Bij de regeling van het koolstofdioxidegehalte in het bloed spelen verschillende onderdelen een belangrijke rol. Lees de tekst goed door en noteer de belangrijkste onderdelen hieronder in de tabel.

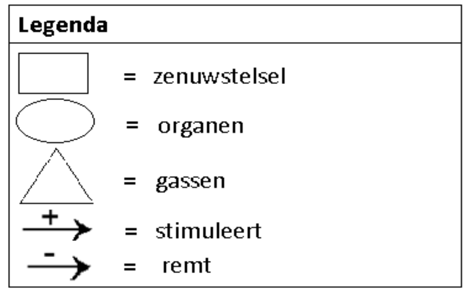
b. Noteer nu bij a achter ieder onderdeel wat de functie is.

Onderdelen	**Functie**

c. Probeer hieronder met behulp van pijlen aan te geven wat de relaties zijn tussen de verschillende onderdelen, die je bij a hebt genoteerd. Een voorbeeld van een relatie is: onderdeel A heeft invloed op onderdeel B (A → B).

Houdt er rekening mee dat een onderdeel relaties kan hebben met meerdere onderdelen.

Schema 2:



d. Bij vraag c heb je de relaties tussen onderdelen weergeven met pijlen. Om de relaties meer te schematiseren, ga je gebruik maken van symbolen (+ en -) en woorden. Deze noteer je bij de getekende pijlen.

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Vraag 3: Zoek de overeenkomsten

Je hebt de eerste twee vragen gelezen en beantwoord. Ondanks dat er twee verschillende situaties beschreven zijn en deze op het eerste gezicht niet op elkaar lijken, zijn er wel degelijk overeenkomsten. Deze overeenkomsten bevinden zich bij de onderliggende processen van beide situaties. Om de onderliggende processen te vergelijken, kun je gebruik maken van de zelfgemaakte schema's 1 en 2.

Kijk vooral naar de algemene overeenkomsten tussen beide schema's en focus niet op de details.

a. Wat zijn de overeenkomsten tussen schema 1 en 2? Noteer alle overeenkomsten die je kunt bedenken.

Maak op basis van de overeenkomsten bij vraag a een algemeen schema. Dit schema moet dus van toepassing zijn op beide voorbeelden.

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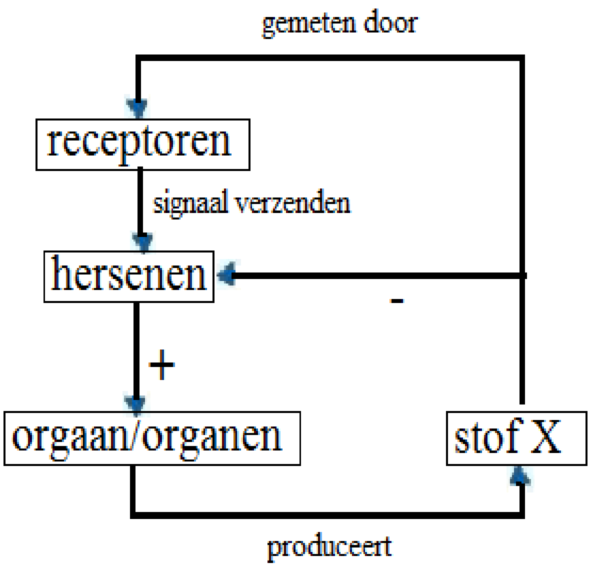
- symbolen (+ en -) en woorden: om relaties te beschrijven

b. Tenslotte, bedenk nu bij het schema van vraag b een passend voorbeeld, zoals die bij vraag 1 en 2. Leg jouw voorbeeld uit.

Appendix D

The questionnaire for the experimental group

Vragenlijst



Afb. 1. Een algemeen model van een regelkring met negatieve feedback.

De vragen die je net gemaakt hebt, gingen over systemen met regelkringen en feedbackmechanismen (zie afb. 1). Het menselijk lichaam bestaat uit een aantal van deze type systemen. Voorbeelden zijn: regulatie van temperatuur en de hoeveelheid schildklierhormonen. Deze type systemen zorgen voor de handhaving van homeostase, dit betekent dat de interne milieu constant wordt gehouden ondanks schommelingen in de interne en externe milieu. Uit verschillende onderzoeken is gebleken dat leerlingen moeite hebben met het herkennen en begrijpen van regelkringen en feedbackmechanismen. Het doel van dit onderzoek is het bevorderen van herkenning en begrip van regelkringen met een feedbackmechanisme bij havoleerlingen.

1. Waren er punten die jij als moeilijk, onduidelijk of verwarrend hebt ervaren? Zo ja, wat waren die punten.

____

____

____

2. Hebben de deelvragen a t/m d en de tips bij vragen 1 en 2 geholpen om tot een algemeen model te komen van een regelkring met een feedbackmechanisme? Leg jouw antwoord uit.

____

____

____

3. Verwacht je in de toekomst sneller en/of makkelijker een regelkring met een feedbackmechanisme te herkennen? Leg jouw antwoord uit.

____

____

____

Appendix E

Results regarding skill 1: identification of the components

Table 6. The number of students from both conditions (control and experimental) that scored level 0 to level 4 for assignments 1, 2, and 3b (A1 – A3c) during the intervention. The experimental group was provided with guided steps for assignments 1 and 2 to identify the components of the control loops whereas the control group did not have any guidance. For assignments 1 and 2 the maximum number of correct components was eight. For assignment 3b the maximum number of correct components was five.

Number of correct components	**Control group n=16**			**Experimental group n=21**		
	A1	**A2**	**A3b**	**A1**	**A2**	**A3**
1	1	0	1	0	0	1
2	0	0	1	1	2	2
3	0	0	6	0	2	3
4	1	4	0	0	2	1
5	3	2	0	1	6	0
6	1	3	0	5	1	0
7	6	1	0	5	1	0
8	1	0	0	4	0	0