Improving Causal Reasoning in Pre-University Biology Education: A Design Study

Master thesis

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Abstract

Biology students need causal reasoning to understand complex systems, but their causal reasoning is underdeveloped. In this study, causal reasoning is defined as a set of skills to explain phenomena, draw conclusions and implications, and make predictions. A promising strategy to enhance causal reasoning is developing tools that help students to construct a causal map. Systems modelling tools is a class of tools that integrates all three principles of causality (priority, covariance, mechanism) and the four causal dimensions to explain a causal process (agency, interaction pattern, probability, and mechanism). The aim of this study is to evaluate the utility of systems modelling tools in enhancing causal reasoning of pre-university biology students. An intervention was designed and enacted during biology lessons in a Dutch secondary school (grade 11) in a treatment-control group experimental design. The treatment class performed a lesson activity with a causal map, while the control class did a similar activity, but without a causal map. The use of the causal dimensions was monitored with a pretest and posttest, combined with interviews. The treatment class did not improve significantly more than the control class for the agency and interaction pattern, but there was a trend visible. The treatment group showed a little improvement of the probability and mechanism during the lesson activity. It is concluded that it is worthwhile to improve the design of the lesson activity in order to enhance causal reasoning in biology students.

Keywords: causal reasoning; causal maps; causal dimensions; systems modelling tools; biology education

Improving Causal Reasoning in Pre-University Biology Education: A Design Study

Sabelli (2006) encourages the science education community to improve students' understanding of complex systems. A complex system is a nonlinear system consisting of many components that have either a direct or an indirect causal influence on other components, sometimes forming a feedback loop in the system. In biology education, many complex systems can be recognized, such as ecosystems, evolution, global warming, and the human body. Being able to reason causally about complex systems is an important part of understanding the world in a scientific perception (Brewer, Chinn, & Samarapungavan, 2000; Corrigan & Denton, 1996). Causal reasoning can be defined as a set of skills to explain phenomena, draw conclusions and implications, and make predictions (Jonassen & Ionas, 2008; Pazzani, 1991). These skills can help students to grasp the essence of complex systems.

In the scientific field of causal reasoning, causality and causation are not to be confused (Pazzani, 1991). While causality concerns domain-specific causal relationships, causation describes domain-independent principles. The theory of causation is a collection of domain-specific causal relationships in a person's mind to predict a certain outcome from a particular cause or set of causes. For example, every person knows the causal relationship that kicking a stationary ball will lead to movement of the ball. Every person has a different collection of domain-specific causal relationships. For example, not everyone knows that drinking too much water can lead to oedemas in the body, often resulting in death. Some persons do not know what happens when you introduce a new species in an ecosystem, while others are able to make a substantiated prediction.

The theory of causality concerns three domain-independent principles that are essential for any causal process (Hung & Jonassen, 2006; Jonassen & Ionas, 2008). The three principles are the priority principle, the covariation (co-occurrence) principle, and the mechanism principle. The priority principle states that a cause is valid when it precedes the effect temporally. The covariation principle indicates that a causal relationship is legitimate if the association between a cause and an effect occurs repeatedly. The mechanism principle refers to the intermediary events or processes that connect a cause and an effect. It can explain the repeated or constant relation between a cause and an effect.

Grotzer and Perkins (2003, 2005) claim that in causal explanations, four dimensions can be identified: the mechanism, the interaction pattern, the probability, and the agency. The mechanism is about the process of how an event happens. The interaction pattern is about how several events are linked to each other. The probability is about the certainty that each event happens, influenced by conditions and ratios. The agency is about who or what caused a certain event. These four dimensions are not mutually exclusive (Grotzer, 2003). The mechanism can be seen as a combination of the agents, interaction pattern, and probability. Agents are part of the interaction pattern: the more agents, the more elaborate and/or complex the interaction pattern becomes.

In biology education, students' causal reasoning is often underdeveloped. This is visible from primary education to university (Abrams & Southerland, 2001; Bishop & Anderson, 1990; Grotzer, 2003; Grotzer & Bell Basca, 2003; Grotzer, Solis, Tutwiler, & Cuzzolino, 2017; Perkins & Grotzer, 2005). One problem is that students are often not able to distinguish causal explanations from functional explanations (Bishop & Anderson, 1990). One of the reasons is the tendency to mention an action or characteristic as it is intentional, whether it concerns a person, animal or inanimate object (Grotzer, 2003). This way, the explanation becomes functional rather than causal.

Another problem is that when a student does give a causal explanation, it is often too simplified. Regarding the interaction pattern, students tend to use discrete and simple linear causality when it actually is more complex (Feltovich, Spiro, & Coulson, 1993; Green, 1997; Perkins & Grotzer, 2005). Moreover, interaction patterns are treated as an exact replica of a prototype version, not realising that patterns change in different situations and that there are differences in agents and how they act on each other (Feltovich et al., 1993). Concerning agency, students tend to look for direct and local agents and do not take indirect or remote agents into account (Grotzer, 2003). Students also have the tendency to be deterministic in their causal explanation, ignoring the existence of probability (Grotzer et al., 2017). When looking at the whole mechanism of a process, students have difficulties with combining interaction patterns that form the mechanism (Feltovich et al., 1993). Despite all these reported difficulties concerning students' causal reasoning, Grotzer et al. (2017) found that students do have the potential to improve their causal reasoning. By developing strategies to nurture this potential, students can enhance their causal reasoning in order to better understand complex systems.

Jeong and Lee (2012) argue that causal reasoning can be supported by constructing causal maps. By constructing causal maps, students can visually present their understanding of complex systems and the causal processes in these systems. Constructing causal maps is part of Modelling-based Learning, a learning approach where students construct models as representations of physical phenomena (Louca & Zacharia, 2012). Many researchers have created tools for causal maps for their research on causal reasoning, many times using a software tool (Chi, Roscoe, Slotta, Roy, & Chase, 2012; Guerram, Maamri, & Sahnoun, 2010; Jeong, 2010; Jeong & Lee, 2012; Jonassen & Ionas, 2008).

Jonassen and Ionas (2008) presented a class of tools called systems modelling tools, which integrates all three principles of causality. Unintentionally, the four causal dimensions are visible in the tools as well. Students using systems modelling tools make a map of a process or system with a simple set of building block icons: stocks, flows, converters and connectors. Stocks illustrate the level of the causal agents. Flows show the effects of these agents on each other. Stocks and flows combined show the interaction pattern of a system, including cyclical relationships when present. Converters are coefficients or ratios influencing flows, adding probability in the map. Connectors are arrows through the whole map that show the directional effect of agents and converters. All these building block icons together show the mechanism of the process. Figure 1 shows an example of a causal map that is made with the building block icons of systems modelling tools. The squares are stocks; the circles between the squares are flows; the other circles represent converters; the red arrows are connectors.

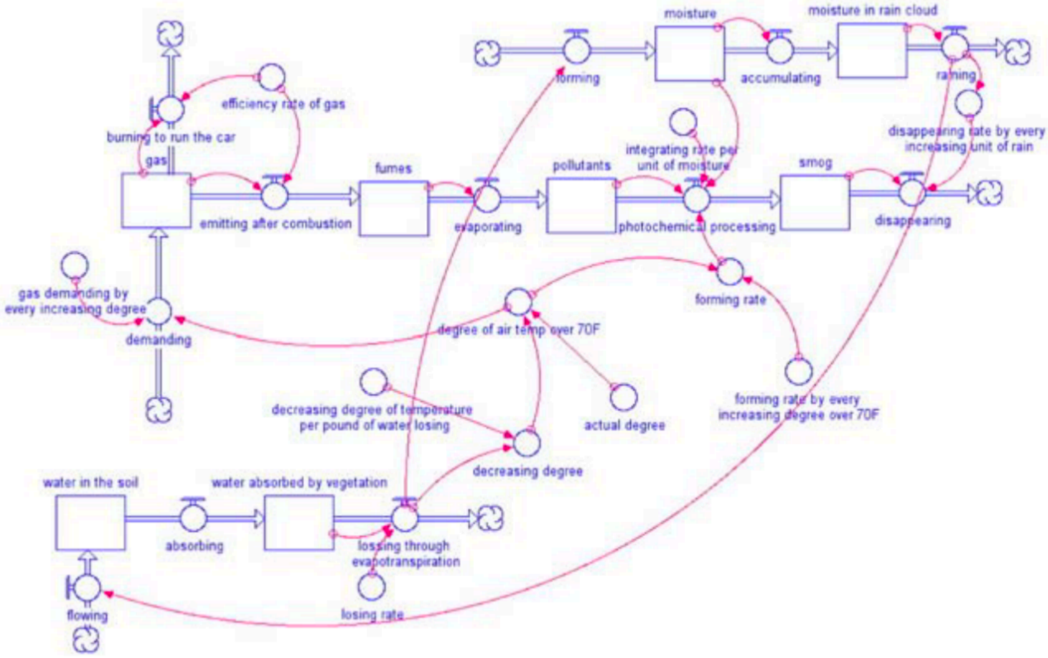

Figure 1. An example of a causal map made with the building block icons of systems modelling tools (from Jonassen and Ionas, 2008, p. 305)

According to Jonassen and Ionas (2008), systems modelling tools are the most promising class of tools for enhancing causal reasoning, because it is the only class that enables students to add both covariational and mechanistic attributes in their causal map. Due to the theoretical foundation, systems modelling tools indeed seem to show potential for enhancing causal reasoning. However, Jonassen and Ionas (2008) also say that there is little empirical research on instructional methods for supporting causal reasoning. This means that there is not much data on how systems modelling tools can be instructed effectively to students. This study wants to investigate how systems modelling tools can be used in pre-university. For this study, a lesson activity is designed based on systems modelling tools. The aim of this study is to evaluate the utility of systems modelling tools in enhancing causal reasoning of pre-university biology students. The study focuses on two questions:

1. To what extent does the designed activity enhance each of the four causal dimensions, e.g. agency, interaction pattern, probability, and mechanism?
2. How do students experience the lesson activity with respect to the causal map and the setup of the activity?

The method that is used for this study, is design research. Design research as a method is relatively new, but it is an accepted paradigm of educational research (Bakker, 2018; Bakker & Eerde, 2015; Sandoval, 2014). Applying design research, this study combines two goals: 1. contributing to fundamental knowledge about enhancing causal reasoning in the context of biology and 2. contributing to the development of lesson material that support causal reasoning. Many design studies contain multiple cycles of design, implementation, and evaluation. As this study is part of a master's programme, one cycle is conducted. Suggestions for redesigning the lesson activity for a second cycle are described in the discussion.

Methods

Participants

The participants were Dutch upper secondary biology students, age 16-17, grade 11. Two classes were used: one of 24 students and one of 25 students. Both classes were from the same school. The school, the teachers and the students agreed on participating in the study. Because all students were 16 or 17 years old, they did not need consent from their parents or guardians. For formality, the parents and guardians were informed about the study and the participation of their child.

It was randomly decided that the class of 24 students became the treatment class and the class of 25 students became the control class. Because the lesson activity was designed as a group task, both classes were divided in groups. The treatment class was divided in groups of three, resulting in eight groups. The control class was divided the same way, except there were also two groups of two. Therefore, this class contained nine groups. This means that the total sample size consisted of 17 groups. The grouping of the students was decided randomly. To make sure every student combination would not cause problems in the classroom, the teachers of the classes checked the combinations. The teachers approved all groups, therefore no changes needed to be made. The groups were named from T1 to T8 (treatment class) and from C1 to C9 (control class), to ensure that the students remained anonymous.

Design Lesson Activity

The lesson activity was designed around the biology topic that the students needed to learn at the end of their curriculum year: muscle contraction. The lesson activity of the treatment class was based on the systems modelling tools described by Jonassen and Ionas (2008). It was redesigned in a way, that the four causal dimensions were more easily recognizable, and that the lesson activity was easy to understand for pre-university students.

The goal of the lesson activity was to make a causal map that represents the process of muscle contraction. Like the design of Jonassen and Ionas (2008), the causal map consists of stocks, flows, converters and connectors. Figure 2 shows an example that the students of the treatment class received of how the causal map works. The figure is in English; the students received the example in Dutch. Each building block has a different colour, in order that students can easily recognize and distinguish them. The blue parts are the stocks (the agents of a mechanism). The green parts are the flows. The stocks and flows are connected with black arrows. This combination represents the interactions patterns. The pink parts are converters (conditions and ratios that add probability). The red arrows are connectors. Connectors can come from a converter or a flow, but always leads to a flow. The combination of the building blocks and arrows represent the mechanism.

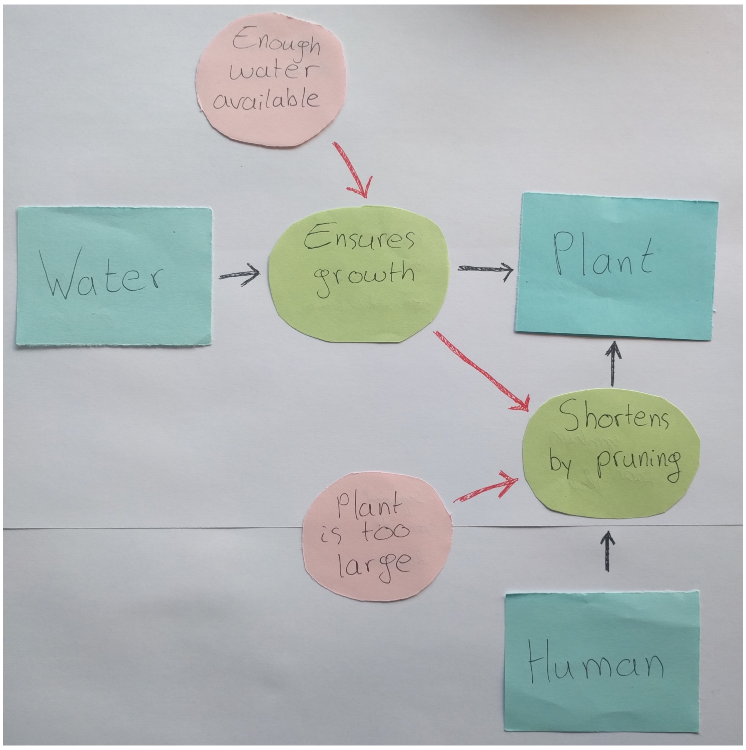

Figure 2. An example of how the causal map of the lesson activity works

To guide students into making the mechanism of muscle contraction, they were given a worksheet that contained a brief explanation of how the causal map works, questions about muscle contraction, and tasks to make the causal map step by step (see appendix 1, in Dutch). In this worksheet, the building blocks of the causal map were given a Dutch translation. The building blocks were given names that would be easy to understand for the students, as they did not need to know the scientific terms of the lesson activity. The causal map itself was named a scheme towards the students.

The control class received a control version of the worksheet. It contained the same questions about muscle contraction as the worksheet of the treatment class. However, the worksheet did not contain an explanation on the causal map and no tasks about making the causal map. Instead, they needed to write down the process of muscle contraction at the end of the activity. Appendix 2 contains the worksheet that the students of the control class received (in Dutch).

Figure 3 shows a causal map that represents a part of the mechanism of muscle contraction. This causal map serves as a threshold. The expectation was that the groups of the treatment group would make a causal map that looked similar to the threshold causal map. Inside the muscle fibers, there is another complex causal process that the students needed to understand. For the lesson activity, it was expected that they could at least show a part of that process in the causal map.

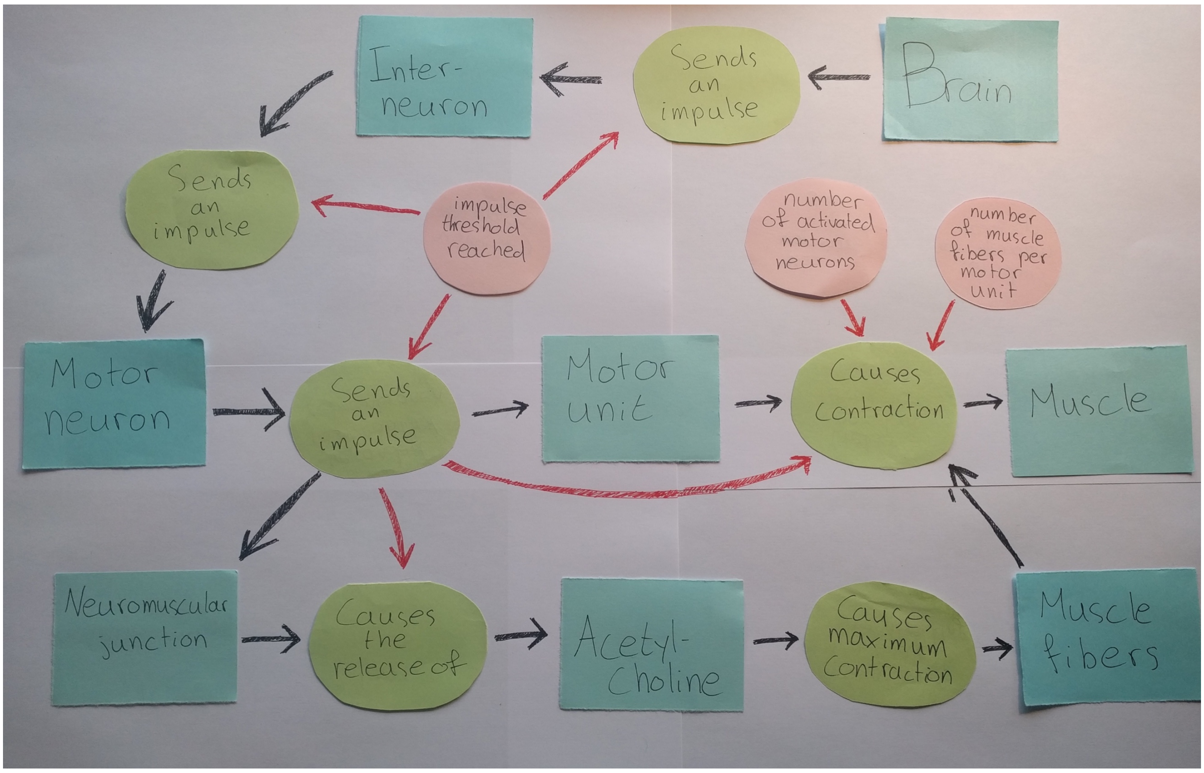

Figure 3. Threshold causal map

Conjecture Map of the Design

During the design of the lesson activity, the principles of conjecture mapping were taken into account. Conjecture mapping is a technique that conceptualizes a design research study, explained by Sandoval (2014). By articulating the lesson activity in a conjecture map, the design of the lesson activity can be combined with the theoretical arguments behind the design. A conjecture map also enables the designer to make predictions on the learning processes and learning outcomes, and to evaluate these predictions after the lesson activity has been carried out.

A conjecture map contains four parts. It begins with a *high-level conjecture*, which forms the theoretically based idea of how to support a specific learning process in order to reach a specific outcome. This *high-level conjecture* is reified in the second part, the *embodiment* of the specific design. This part elaborates on describing the elements of the lesson activity. The third part contains the *mediating processes*: the expected interactions with the lesson activity and the visible learning processes. How the elements of the *embodiment* are connected to the *mediating processes* can be articulated as *design conjectures*. The expected learning processes will lead to certain *outcomes*, representing the fourth part of the conjecture map. How *mediating processes* lead to the *outcomes* are shown by *theoretical conjectures*.

Figure 4 shows the conjecture map of the designed lesson activity for the treatment class. It is focused on the activity of making a causal map. Concerning the *high-level conjecture*, the desired outcome of the lesson activity is that the students improve their causal reasoning. To achieve this, the students can practice on applying the causal dimensions described by Grotzer and Perkins (2003, 2005), by using the building blocks of the systems modelling tools of Jonassen and Ionas (2008). When the students improve in using the causal dimensions, it can be said that they improve their causal reasoning. The elements in the design of the causal map are the *embodiment* of the lesson activity. The arrows of the *design conjectures* show how each element had effect on the expected *mediating processes*. The arrows of the *theoretical conjectures* show which mediating process should lead to which *outcomes*.

Procedure of the Intervention

The intervention in the two classes took four weeks, from May to June 2018. Each class participated seven lesson hours: one hour for an introduction, two hours for the pretest

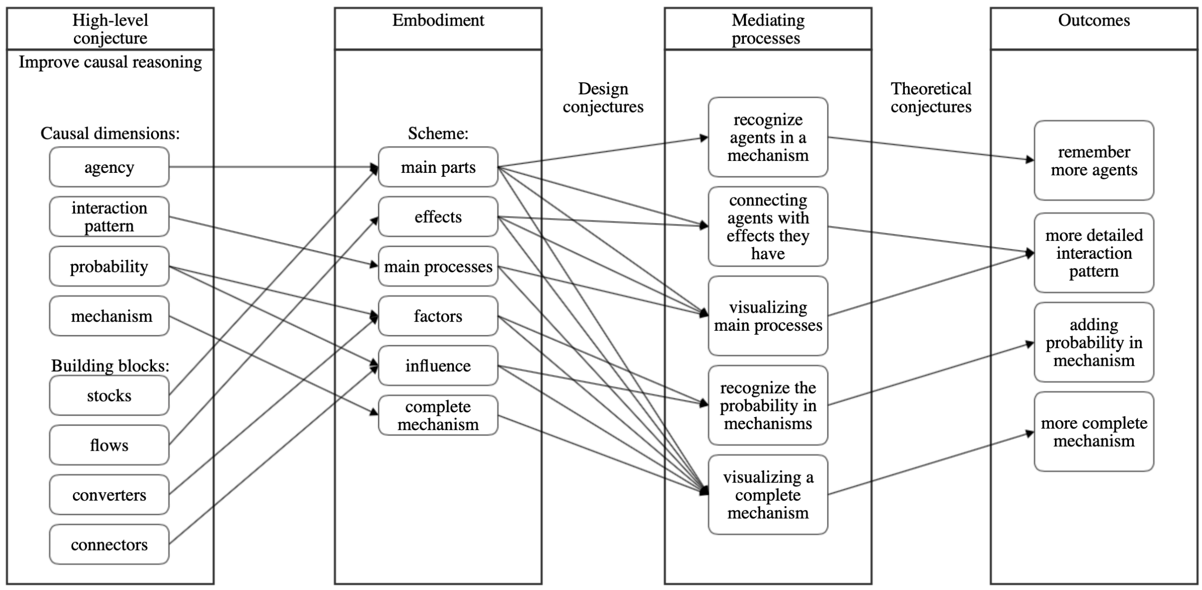

Figure 4. Conjecture map of the designed lesson activity for the treatment class

and interviews, one hour for the lesson activity, one hour for evaluating the lesson activity, and two hours for the posttest and interviews. The procedure in these lesson hours is the same for both the treatment and control class, except for the lesson activity and the evaluation of this activity. An overview of the different phases in the intervention is shown in table 1.

In the first week, the students were introduced to the study. This included an explanation of what was expected of the students during the following weeks. After the introduction, which took ten to fifteen minutes, students were asked to individually read the paragraph about muscle contraction in their textbook and write down the important terms and their definitions. At the end of the lesson hour, they needed to hand in the list of terms, and they were only allowed to go home after the list was approved by the researcher. This small activity introduced the students to the concept of muscle contraction, so that they could do the pretest with some prior knowledge.

The pretest (appendix 3) was carried out in the second week. The test began with short questions to stimulate the prior knowledge of the students. At the end of the test, there were two questions where the students needed to describe the whole mechanism of muscle

Table 1
Overview of the Intervention

Week	Phase	Procedure
1	Introduction	Explained the study to the students and explained what is expected of them. Students individually read the paragraph about muscle contraction in their textbook and wrote down the important terms and their definitions.
2	Pretest and interviews	All students made a test on paper in their assigned groups. Per class, three groups were interviewed about their answers on the test.
3	Lesson activity	The groups of the treatment class enacted the designed lesson activity. The groups of the control class enacted the control version of the lesson activity.
4	Evaluation lesson activity, posttest, and interviews	Teachers of both classes discussed the lesson activity with their students and provided the correct answers. The groups of the treatment class were shown an example of a causal map on muscle contraction. All groups made the same test on paper as they did in the pretest. Per class, two groups were interviewed about their answers on the test.

contraction, from brain to sarcomeres (a structure inside the muscle fibers). After the pretest, three groups of each class were interviewed to gain more insight into the answers that were written down on the test. The groups who were not interviewed, followed a lesson by their teacher about a different topic, according to their regular curriculum.

The lesson activity took place in the third week of the procedure. The treatment class used paper materials and markers to make a causal map of the mechanism of muscle contraction, guided by the instructions on the worksheet. The questions that were asked on the worksheet, could be answered by writing on the worksheet itself. The control class did a similar lesson activity, but they only received a worksheet that contained the same questions, without instructions of making a causal map. Because the groups of the control class were expected to finish the task earlier than the treatment class, they were allowed to answer the questions about muscle contraction in their textbook after they finished the activity. These were basic questions to understand the concept of muscle contraction and did not give new information on the subject. Therefore, it should not have had effect on the posttest. Five groups in the treatment class were shortly interviewed during the lesson activity, to ask about their experience with the lesson activity.

In the last week, both classes attended a lesson hour where the teacher discussed the lesson activity and provided the correct answers. Students were allowed to ask questions and take notes. The students of the treatment class were also shown an example of what a causal map about muscle contraction could look like. Later that week, the posttest and interviews were carried out. The procedure was the same as the pretest: it contained the exact same written test and the same protocol for the interviews. Because the school could not afford much time in the last week, only two groups of each class were interviewed. the groups that were chosen for the interviews were the same groups that were interviewed after the pretest, too see whether there was any development in their understanding of muscle contraction. The groups that were not interviewed, followed a lesson about a different topic according to their regular curriculum.

Data Collection and Analysis

The raw data consists of the pre- and posttest, the audio of the interviews, the answers on the worksheets of the lesson activities, the audio of the short interviews that was recorded during the lesson activity of the treatment class, and photos of the causal maps that the students of the treatment class made. All paper material was scanned and digitalised.

In order to find out to what extent the four causal dimensions improved in the two classes, the collected data needed to be quantified for statistical analyses. Therefore, the pre- and posttest, the interviews, and the worksheets were coded in a coding scheme. Appendix 4 contains the coding scheme that is used. Because the mechanism is a combination of the other three causal dimensions, only the agency, interaction pattern, and probability were implemented in the coding scheme. The coding of each dimension began with a count of the number of agents, steps in the interaction pattern, or conditions or ratios that add probability. Descriptions were added to each count, using quotes and brief summaries of the raw data. To determine the quality of each dimension, the counts and descriptions were interpreted by answering questions on how the dimension was used. Using these interpretations, it was decided whether each dimension was used similarly to the threshold causal map. When a dimension was indeed used as expected, this dimension would receive a pass.

Three coding schemes were used for each group: one for the pretest and the additional interviews, one for the lesson activity, and one for the posttest and the additional interviews. All 51 coding schemes were coded by the same researcher. To check the reliability of the coding protocol, the supervisor of this study coded four coding schemes. There was an 87.5% match. The mismatches were mostly due to a difference in judgement of whether the agents and their effects were correct. All differences were discussed and after reaching a mutual agreement, it was concluded that the protocol was reliable.

The first question of this study is to what extent the lesson activity enhances the four dimensions of causal reasoning. To answer this question, the coded data of the pre- and posttest of both classes were compared to each other. It was decided that the coded data on the interviews would not take part in the statistical analysis, because not all groups were interviewed. In de coding schemes of the pre- and posttest, it appeared that there was almost no data on the probability. It is possible that the pre- and posttest did not stimulate the students enough to add probability in their answers. Therefore, it was decided that this causal dimension would not be part of the statistical analyses; only the agency and interaction pattern were statistically analysed. A MANOVA was performed to analyse the difference between the treatment class and the control class concerning the number of agents and the number of steps in the interaction pattern. Both classes were expected to be able to name more agents and steps in the posttest compared to the pretest. However, the treatment class was also expected to name more agents and steps than the control class. In other words: the difference between the pretest and posttest was expected to be higher in the treatment class compared to the control class. Two χ^2 tests were performed to analyse the proportions of groups that received a pass on the posttest for the agency and interaction pattern (no group received a pass for any dimension in the pretest). The treatment class was expected to have a higher proportion than the control class. All tests were performed with $\alpha = .05$ as criterion for significance.

Besides analysing the coded data of the pre- and post-test, it was also examined to what extent the four causal dimensions were enhanced during the lesson activity. The coding of the lesson activity was a combination of the worksheet and the causal map. However, after the coding had already been performed, it seemed more useful to only look at the causal maps, because the causal maps served as the end products of the lesson activity. Therefore, each causal map was analysed a second time. This time, it was a qualitative analysis, without the coding scheme. The quality of each causal map was compared with the threshold causal map. The causal maps were expected to look like the threshold causal map, with similar use of the four dimensions.

The second question of this study is how students experienced the lesson activity with respect to the causal map itself and the setup of the activity. The audio material of the lesson activity and the interviews of the posttest were used in order to answer this question. Only the audio material of the treatment class was used; the control class did not make a causal map, therefore it was not considered necessary to examine their experience on the lesson activity in order to answer the second question of this study. Because most audio files were around ten minutes, it was not considered necessary to transcribe the files. The quotations that are used in the results section were translated directly from the audio files, from Dutch to English. Table 2 shows the codes that the audio files received to refer to in the results section.

Results

Course of the Intervention

As explained in the methods section (table 1), the intervention consisted of several phases. During the introduction, everything went according to plan. In both classes, the

Table 2
Codes of the Audio Files

Phase of the intervention	Group number	Code
Lesson activity	4	LA4
Lesson activity	5	LA5
Lesson activity	6	LA6
Lesson activity	7	LA7
Lesson activity	8	LA8
Interview posttest	5	IP5
Interview posttest	7	IP7

students listened to the introduction of the study, read the paragraph about muscle contraction and wrote down the important terms and their definitions. However, they might not have paid much attention to those important terms, because the students still had difficulties with answering the questions of the pretest. The pretest went well, except for the fact that many groups in both classes were not able to answer the last question on the pretest, which was the second large question that was meant for analysis. There are two possibilities why that might have happened: the first explanation is that the students did not have enough time to finish the test; the second explanation is that the prior knowledge of the students was not enough to answer the question. The interviews after the pretest went according to plan.

The lesson activity in both classes went without large complications. All groups worked on the lesson activity and followed the instructions on the worksheet. However, it was noticeable that in some groups, two students did most of the work and one student was not fully participating. The students who were not participating, tended to talk to other students outside their groups or use their phone. Another point of attention was that the groups of the treatment class did not have enough time to fully finish the lesson activity. At the end of the lesson hour, the groups needed to make the best out of their causal map and were not able to represent the mechanism as they could have. Most groups did not have enough time to show the mechanism inside the muscle fibers. The groups in the control class were able to finish the lesson activity. After they finished, they were supposed to answer the questions about muscle contraction in their textbook. However, instead most of the students were just talking to each other or using their phone. Although not everything went according to plan during the lesson activity, it still provided enough data to analyse the enhancement of causal reasoning with respect to the four causal dimensions.

The evaluation of the lesson activity went according to plan. In both classes, student made notes on the correct answers of the lesson activity. The posttest went without any difficulties, although there were again multiple groups in both classes who were not able to answer the last question. A possible explanation is that this questions was in an unfamiliar context. This context might have been too difficult to comprehend, even after the lesson activity. The interviews after the posttest went according to plan.

Enhancement of the Causal Dimensions

Figure 5 shows of both classes the mean difference between the posttest and the pretest regarding the number of agents and the number of steps in the interaction pattern. Both classes were able to name more agents and steps in the posttest than in the pretest, which was expected. The treatment class named almost twice as much more agents and almost twice as much more steps than the control class, which was also expected. However, these differences between the treatment and control class were not significant (MANOVA, $F(.38) = .05$, $p = .35$).

The number of agents or steps does not necessarily correlate with an improvement of describing the mechanism. For example, more agents do not mean a better description of those agents (or even using correct agents). Figure 6 shows the proportion of groups in both classes that received a pass for the agency and interaction pattern in the posttest. The proportion of groups that received a pass was larger in the treatment class compared to the control class for both dimensions, which was expected. However, these differences were not significant for both the agency ($\chi^2(1, N = 17) = 1.52$, $p = .11$) and the interaction pattern ($\chi^2(1, N = 17) = 0.02$, $p = .44$).

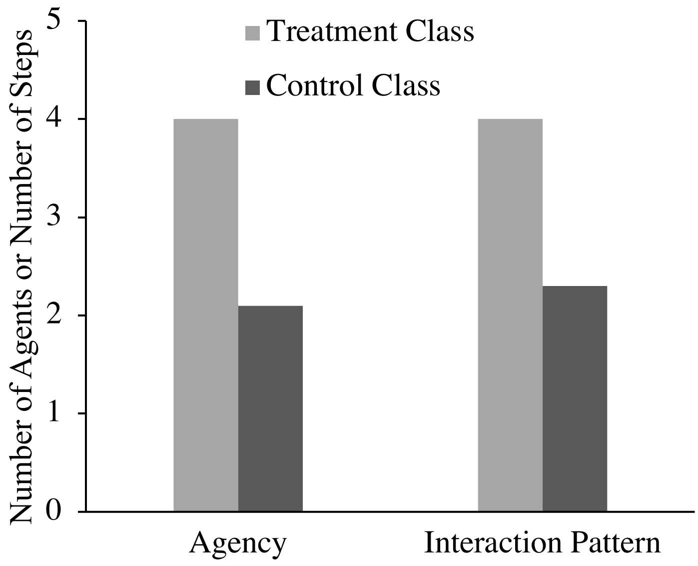

Figure 5. The mean difference (in number of agents and steps) between the posttest and the pretest of the treatment class and the control class

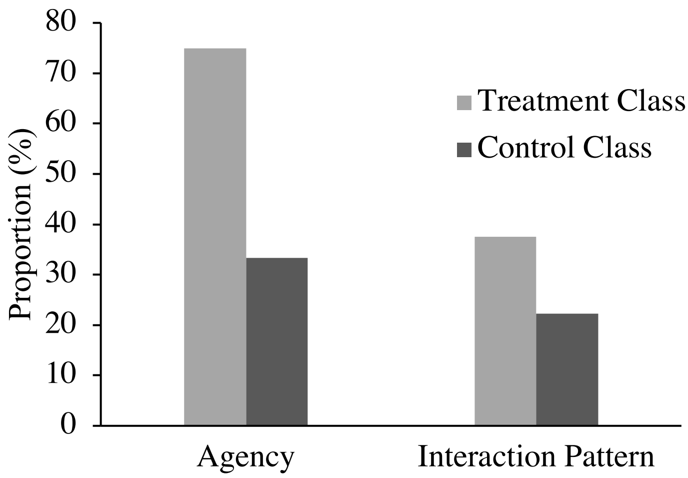

Figure 6. Proportion of groups (in %) that received a pass for the agency and interaction pattern in the posttest

Although none of the statistical tests were significant, there is a trend visible: the treatment class always performed better than the control class regarding the agency and interaction pattern.

The causal maps of the treatment class were studied to examine whether students' causal reasoning was enhanced during the lesson activity itself. The causal maps were compared with the threshold causal map in the methods section. It was expected that the causal maps of the students would be similar to the threshold causal map, using the four causal dimensions in a similar way. Figure 7 shows a causal map that one of the groups (group 3) made. This map will be used as an example to show how each causal map was analysed.

Figure 7. Causal map that one of the groups (group 3) of the treatment class made during the lesson activity

For the agency, the agents must be correct, there should be no agents missing, and there should be some agents of the process inside the muscle fibers. These are criteria to be met when compared to the threshold causal map. The following eight agents should be present: brain, interneuron, motor neuron, motor unit, neuromuscular junction, acetylcholine, muscle fibers, and muscle. In figure 7, seven out of eight agents are present. Only one agent is missing. Therefore, this criterium meets the threshold. In total, there are ten agents in the causal map. Two agents are not correct, but all the other agents are correct, which is enough to meet the threshold. There should also be some agents present that are part of the process inside the muscle fibers, but this is not the case. Therefore, this criterium does not meet the threshold.

For the interaction pattern, there are three criteria: there needs to be a multiple linear interaction pattern, the pattern must be correct, and there should be no gaps in the pattern. The causal map in figure 7 has a multiple linear interaction pattern, therefore this criterium meets the threshold. However, the two patterns are wrongly connected to each other: the map shows that muscle fibers have effect on a motor neuron, while it is actually the other way around. Moreover, in the pattern with only agents, these agents do actually not influence each other as this map suggests. However, the other interaction pattern is correct. Therefore, the criterium for a correct pattern partly meets the threshold. There are two important steps missing in the pattern compared to the threshold causal map, but besides that, there are no gaps in the pattern. Therefore, the criterium for no gaps partly meets the threshold.

For the probability, the criteria are that the conditions and ratios should be correct and no conditions or ratios should be missing. According to the threshold causal map, the condition that the impulse threshold is reached, influences all steps where an impulse is sent. Contraction of the muscle is influenced by two ratios: the number of activated motor neurons and the number of muscle fibers per motor unit. The condition that the impulse threshold is reached, is present in the causal map of figure 7, but this condition influences only two of the four steps where an impulse is sent. Two ratios influence the muscle contraction in the map, but those are different than the threshold. One ratio is incorrect, the other is partly correct. Because of this, the criterium for correct conditions and ratios only partly meets the threshold. Because the ratios of the threshold are missing, the criterium for nothing missing is not met.

For the mechanism, the overall mechanism should be similar to the threshold and there should be a part of the mechanism inside the muscle fibers present. When looking at the evaluation of the other dimensions, the mechanism in figure 7 resembles the threshold to a certain extent, but not enough. Therefore, this criterium does not meet the threshold. There is no part of the mechanism inside the muscle fibers present, therefore this criterium also does not meet the treshold.

Table 3 to 6 how each group in the treatment class used each causal dimension in comparison with the threshold causal map. When a criterium is met, it is checked with the symbol +; when a criterium is not met, it is checked with a –; when a criterium is partly met, it is checked with a ±.

Experience of the Lesson Activity

In general, the interviewed groups understood how to do the lesson activity. There were some complaints about the clarity of certain instructions in the worksheet, but these instructions were clear after a brief explanation. Two other groups mentioned that the lesson activity was challenging, but understandable. All interviewed groups thought that they were learning the process of muscle contraction by making the causal map. One student mentioned (LA8): “You are working more active with the concept. More than you would do yourself, I think.” Another student said (LA6): “This way, you clarify the concept better than when you are just reading it.” This means that these students saw benefit in making a causal map. However, two groups mentioned that they did not know whether they thought in the right

Table 3

Use of the Agency

Group	Correct agents	No agents missing	Agents inside muscle fibers
1	+	–	±
2	+	+	–
3	+	+	–
4	+	+	–
5	+	–	±
6	+	±	–
7	+	±	±
8	+	–	–

Table 4

Use of the Interaction pattern

Group	Multiple linear pattern	Correct pattern	No gaps in the pattern
1	–	+	–
2	±	+	±
3	+	±	±
4	+	+	–
5	+	+	–
6	–	+	±
7	–	+	±
8	–	+	–

Table 5

Use of the Probability

Group	Correct conditions/ratios	No conditions/ratios missing
1	±	–
2	+	–
3	±	–
4	–	–
5	±	–
6	–	–
7	±	–
8	±	–

Table 6

Use of the Mechanism

Group	Correct mechanism	Mechanism inside muscle fibers present
1	–	±
2	±	–
3	±	–
4	±	–
5	±	±
6	–	–
7	±	±
8	–	–

direction or not. They were afraid that they did it wrong and that they would remember the concept incorrectly.

When asking about their opinion on the lesson activity, all interviewed groups said the activity was fun and different from what they usually did, in a positive way. One student remarked (LA6): “It is more fun than working on your own. And now […], because you do it in a group, you really have to do it, because other people are also dependent on you. And otherwise, on your own you don't really have that motivation or something.” This indicates that the student enjoyed making the causal map in a group. Another student found the lesson activity difficult compared to the usual lessons (LA5): “Well, I find [the task] in itself a bit difficult, because normally, the teacher just explains how something works and then, then you can just, uh, apply that to these tasks that you normally have in the book. But now you have to find out for yourself how everything works.” Another student of the group added: “Yes, now you're being thrown a bit into the deep, so to speak. Good luck.” The fact that they were thrown in the deep, felt frustrating for these students, because they were not familiar with making a causal map. However, they also remarked that when they would know how to make the causal map, it would be fun to do. This indicates that these students felt uncomfortable with making a causal map, because they were unfamiliar with the activity, but that they also realised that it would be fun to do when they became more familiar with it.

During the interviews of the posttest, the students were asked about their afterthoughts on the lesson activity. One student (IP5) mentioned that the causal map only made sense after the teacher explained the concept in the lesson after the lesson activity. In another group (IP7), one student said that the causal map helped to gain an overview; he saw something visual thanks to the causal map. The other student of the group did not really find the causal map helpful. She explained that she loses the overview when she has to connect things with each other, because everything gets mixed up. She prefers a summary over a causal map.

During the lesson activity and the interviews of the posttest, there were several suggestions from the students on how to improve the lesson activity. The clearest suggestions were: a lecture about the concept before they have to make the causal map, for a better understanding of the concept while making the map; filling in some pieces beforehand, so that the students can built the causal map around those pieces; make a drawing of the process additional to making the causal map; and keeping the examples about how the causal maps work.

Discussion

The aim of this study was to evaluate the utility of systems modelling tools in enhancing causal reasoning of pre-university biology students. In order to do this evaluation, two questions were formulated:

1. To what extent does the designed activity enhance each of the four causal dimensions, e.g. agency, interaction pattern, probability, and mechanism?
2. How do students experience the lesson activity with respect to the causal map and the setup of the activity?

Concerning the first questions, conclusions will be drawn by combining the results with the expectations that were illustrated in the conjecture map. In order to answer the second question, only the results are needed. The end of this section contains implications for improving the design of the lesson activity, when a second cycle of this design study would be conducted.

To What Extent Does the Designed Activity Enhance Each of the Four Causal Dimensions, e.g. Agency, Interaction Pattern, Probability, and Mechanism?

According to the statistical tests, the treatment class did not significantly name more agents than the control class did. The number of groups in the treatment class that received a pass for the agency in the posttest, was also not significantly higher than in the control class. This means that there are no indications showing that the lesson activity enhanced causal reasoning with respect to the agency. The interaction pattern had the same statistical outcomes as the agency: the results were not significant, meaning that there are no indications that the lesson activity enhanced causal reasoning with respect to the interaction pattern. However, there is a trend visible that the treatment class performed better than the control class for both the agency and interaction pattern.

It was visible from the causal maps of the treatment class that they understood the concept of agency to a certain extend. Compared to the threshold causal map, all groups used correct agents. However, several groups had not enough agents in their map. Five out of eight groups had no agents that are part of the process inside the muscle fibers, but this might be because the lack of time that the students had. The fact that all groups used the building block for agents (stocks) correctly, shows that the causal map helped the students to recognize the agents in a mechanism, which was an expected *mediating process* in the conjecture map. Moreover, the trend in the statistics suggests that the lesson activity might have helped the students to remember more agents, which is a desired *outcome* in the conjecture map. Therefore, the lesson activity shows potential to enhance causal reasoning with respect to the agency.

The visualization of the interaction patterns was shown differently in each group. This is mainly because each group used the building block for effects (flows) differently. It appears that the groups had difficulties with using this building block correctly. Although it was an expected *mediating process* in the conjecture map that students learned how to visualize the main process of the mechanism, all groups showed gaps in their interaction pattern. The presented pattern itself was in most cases correct, but only half of the groups was able to show a multiple linear pattern. Therefore, the desired *outcome* of a more detailed interaction pattern has not been reached in all groups. Despite this, when looking at the trend in the statistics, it can be said that the lesson activity might help enhance causal reasoning with respect to the interaction pattern.

Regarding the probability, none of the groups implemented all conditions and ratios that were in the threshold causal map. Some ratios were missing, and some ratios that were shown, were not correct. In general, the *mediating process* of recognizing probability in the mechanism did not go as expected, because the ratios of the threshold causal map were not recognized. This might be the cause of the fact that the groups were not able to add probability in the mechanism during the posttest. Therefore, the lesson activity as it is now is not suitable to enhance causal reasoning with respect to the probability.

When looking at the mechanism, none of the groups were able to make a causal map that met the threshold. Five groups came close, but the other three groups had no mechanism that was complete enough. Three groups were able to show the mechanism inside the muscle fibers. It was noticable that in this mechanism, the building blocks were often used differently compared to the rest of the map: agents were written down on flows or in converters. This shows that for the mechanism inside the muscle fibers, the groups found it difficult to use the building blocks correctly. A possible explanation is that this mechanism was more complicated than the mechanism outside the muscle fibers. It is also possible that they simply tried to write down as much as possible when time was running out, without thinking of which building block to use. Nevertheless, when looking at all the causal maps, the expected *mediating process* of visualising a complete mechanism did not occur and the desired *outcome* of a more complete mechanism is not reached yet. Therefore, the lesson activity as it is now cannot enhance causal reasoning with respect to the mechanism.

How Do Students Experience the Lesson Activity With Respect To the Causal Map and the Setup of the Activity?

In general, the students of the treatment group found the lesson activity fun and innovative. Two groups also saw explicit benefit in making the causal map, understanding the concept better. However, whether the causal map was beneficial or not, depended on the student. For example, one student found the causal map not useful at all, as she lost the overview. There were more students who found the task of making a causal map difficult, but it interested them too. The largest drawback of the causal map was that some students felt uncomfortable with not knowing if they were doing it correctly or not. Besides this, there were no large complaints. Considering the overall opinion, it can be concluded that most of the students had a positive experience with the lesson activity with respect to the causal map.

In general, the students liked the setup of the lesson activity. Some of the students explicitly liked the aspect of working in a group: it was fun to work together, and it gave a feeling of responsibility towards each other. Although the students did not have enough time to finish their causal maps, the students were not explicitly bothered by the lack of time. It was highly preferable that the lesson activity would be combined with a lecture on muscle contraction beforehand, instead of afterwards. In general, the students had a mixed experience with the lesson activity with respect to the setup of the activity: they liked the group aspect, but they missed a lecture on the concept beforehand.

Implications

In conclusion of the first cycle of this design research study, the lesson activity that is based on the systems modelling tools of Jonassen and Ionas (2008) shows potential to enhance the causal reasoning of pre-university biology students, especially with respect to the agency and interaction pattern. However, there are no indications showing that there is a significant difference in improvement between the treatment class and the control class. Nevertheless, it is worthwhile to keep working on the design of the lesson activity, especially when the following implications are applied in the second cycle.

Concerning the data collection, the design of the pre- and posttest needs to be improved to obtain better and more reliable results. It is recommended to leave out the short questions and only keep the two large questions on the whole mechanism. This is because only the two large questions are important for the analyses, and by leaving out the short questions, the students will have more time to answer the large questions. In the formulation of the questions, it should be added that probability should be part of the answers, to remind the students of this.

Furthermore, a larger sample size is needed to collect more data for more trustworthy statistical tests. Therefore, more classes are needed in the second round. Because the lesson activity itself also needs adjustments, it is preferable that the number of classes is not too high yet. This way, the emphasis still lays on the qualitative effect of the lesson activity and the adjustments it received. It is up the researcher how many treatment and control classes are preferred. For the analysis of the data, it might be worthwhile to also count all agents, steps of the interaction pattern, and conditions and ratios of the probability together per class, besides analysing them seperately. This total count might show other differences between the treatment and control classes.

Besides collecting data on the experience of the students, it might be worthwhile to also ask the teachers about their experience. It is important that the teachers are comfortable with using the causal map in their lessons. Therefore, it is advised to also interview the teachers, besides the students.

Concerning the lesson activity, the worksheet needs some adjustments to guide the students better in making their causal map. The building block icons need a more detailed description, especially the flows. It might help the students to better understand how to make their causal map. Moreover, more examples should be added of how to use the building block icons, especially how to use the converters and connectors. This might inspire the students to use these building block icons more consistently. There are also two optional improvements to test whether this increases the feasibility of the lesson activity: fill in some agents beforehand, and let the students make a drawing of the process, besides making the map.

Concerning the setup of the lesson activity, it is highly advised to do the activity in two lesson hours instead of one (in other words, a hundred minutes instead of fifty minutes). With this adjustment, the students will have more time to work on their causal map, resulting in a more detailed interaction pattern and mechanism. It is also advised to arrange the students in groups of two instead of three. This might prevent that one student in a group will not participate. Moreover, the sample size will be larger this way. It is up to the researcher how large the groups should be, but it is highly recommended to keep it a duo or group activity, as the students appreciated the aspect of working together on the causal map.

This study showed that the lesson activity has potential to enhance the causal reasoning of pre-university biology students, especially in the agency and interaction pattern. When taking the implications into account, the lesson activity needs to be redesigned to also show potential with respect to the probability and mechanism and show even more potential with respect to the agency and interaction pattern. By continuing this study and performing a second cycle, this lesson activity will provide progress towards the enhancement of causal reasoning, and thereby the desire to give students a better understanding of complex systems.

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Appendices

Appendix 1 Worksheet Treatment Class (in Dutch)

Het maken van een schema
Jullie gaan in groepjes een schema maken dat het proces van de hersenen naar spiercontractie laat zien. Door de vragen te beantwoorden en de opdrachten uit te voeren, maken jullie stap voor stap een schema over spiercontractie. De groepjes zijn van tevoren ingedeeld.

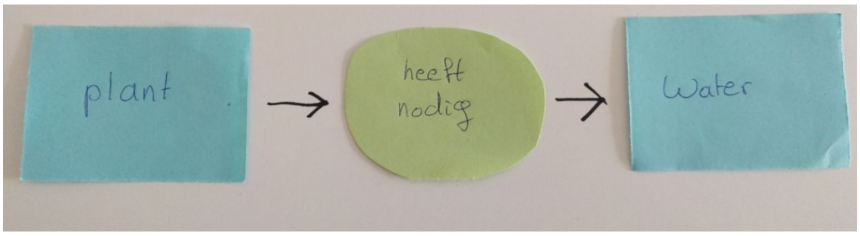
Wat heb je nodig
Voor het maken van een schema krijgen jullie de volgende materialen:
- 6 witte A4-vellen
- 20 blauwe vierkantjes
- 20 groene rondjes
- 20 roze rondjes
- 1 zwarte stift
- 1 rode stift

Hoe werkt het schema
Jullie maken het schema op de A4-vellen. Met een pen van jullie zelf kunnen jullie op de vierkantjes en de rondjes schrijven.

De <u>blauwe vierkantjes</u> zijn de hoofdonderdelen van het biologieproces. Dit kunnen verschillende biologische termen zijn, zoals (delen van) organismen, moleculen en anorganische objecten. De hoofdonderdelen hebben invloed op elkaar. Hoe een onderdeel invloed heeft op een ander onderdeel, is het effect tussen deze onderdelen. Dit effect kunnen jullie beschrijven in de <u>groene rondjes</u>. Met de <u>zwarte stift</u> kunnen jullie pijlen trekken van onderdeel naar onderdeel, in de richting dat het effect plaatsvindt.
Voorbeeld:

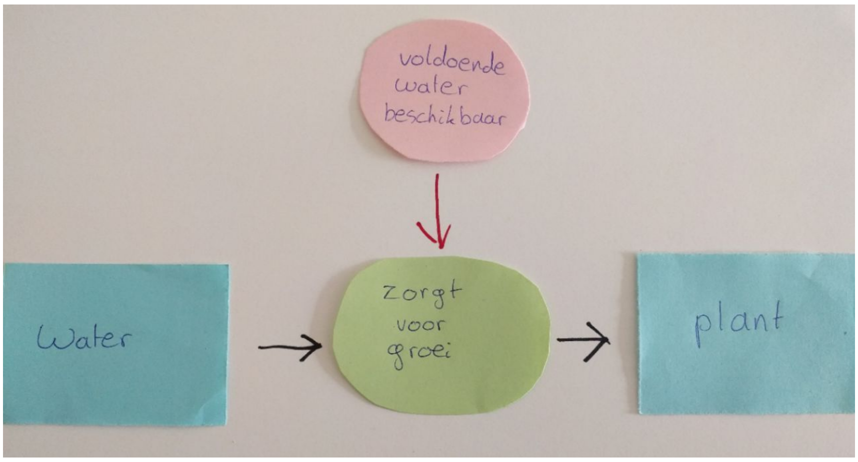
In het voorbeeld zijn ‘water’ en ‘plant’ hoofdonderdelen. Water heeft invloed op de plant: het zorgt voor de groei van de plant. ‘Zorgt voor groei’ is dus het effect dat de twee hoofdonderdelen met elkaar verbindt. Omdat water invloed heeft op de plant, wordt een pijl getrokken van ‘water’ naar het effect ‘zorgt voor groei’, en van het effect naar ‘plant’.
De hoofdonderdelen (blauwe vierkantjes) en de effecten (groene rondjes) vormen gezamenlijk het hoofdproces, inclusief de richting van het proces (zwarte pijlen). De richting van een proces hoeft niet lineair te zijn; het kan ook een feedbackloop zijn.

Een voorbeeld hoe het niet moet:



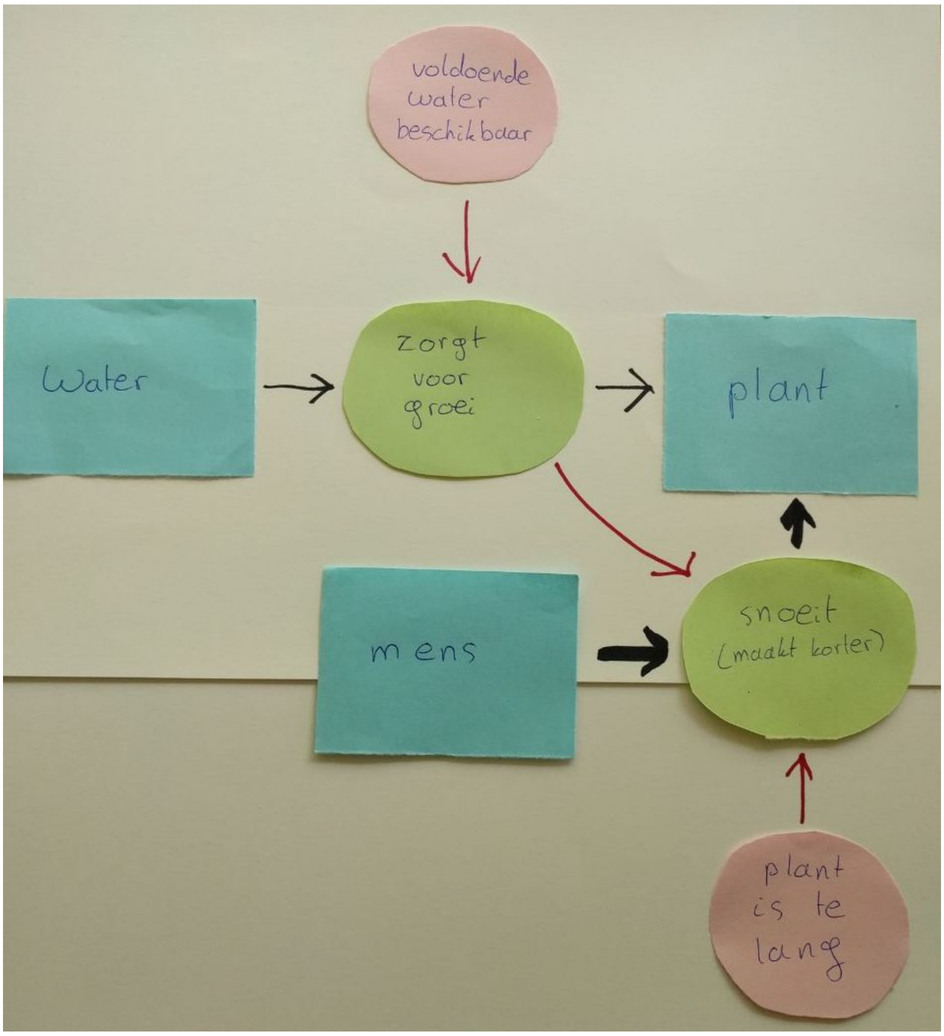
In dit voorbeeld zijn 'plant' en 'water' nog steeds hoofdonderdelen, maar hetgeen dat hun verbindt, 'heeft nodig', is geen effect. Bovendien klopt de richting niet: volgens dit voorbeeld heeft de plant invloed op het water (doordat de plant water nodig heeft). Dit is een onjuiste weergave, omdat de plant niet op deze manier invloed heeft op water.

Er zijn ook factoren die invloed hebben op de effecten. Meestal is een factor een voorwaarde of eis voor het plaatsvinden van het effect. Het kan geen biologische term zijn, omdat alleen hoofdonderdelen biologische termen zijn. De factoren kunnen jullie weergeven met roze rondjes. De roze rondjes hebben invloed op de groene rondjes. Op welk effect de factor invloed heeft, kunnen jullie aangeven met een rode pijl (met de rode stift).
Voorbeeld:



In dit voorbeeld is 'voldoende water beschikbaar' de factor, die als voorwaarde dient voor het effect 'zorgt voor groei'. Omdat de factor (het roze rondje) invloed heeft op het effect (het groene rondje), wordt de rode pijl getrokken van de factor 'voldoende water beschikbaar' naar het effect 'zorgt voor groei'.

Een effect kan ook invloed hebben op andere effecten. Hoe een effect invloed uitoefent op een ander effect, kunnen jullie ook aangeven met een rode pijl.
Voorbeeld:



In dit voorbeeld zie je hoe 'mens' invloed heeft op 'plant'. Het effect is dat de mens de plant 'snoeit'. Dit effect gebeurt alleen als de plant te lang wordt. Vandaar de factor 'plant is te lang'. De mens zal dus niet de plant snoeien als de plant kort is. Maar wanneer water de plant laat groeien, wordt de plant wel te lang. Daarom heeft het effect 'zorgt voor groei' invloed op het effect 'snoeit (maakt korter)'.

Het hoofdproces (hoofdonderdelen en effecten) samen met de factoren en invloeden tussen effecten geeft een volledig beeld van het biologieproces.

Samengevat:
Blauwe vierkantjes → Hoofdonderdelen. Biologische termen, zoals (delen van) organismen, moleculen en anorganische objecten.
Groene rondjes → Effecten. Effecten die hoofdonderdelen op elkaar hebben.
Roze rondjes → Factoren. Voorwaarden of eisen voor het plaatsvinden van effecten.
Zwarte pijlen → Richting welk effect hoofdonderdelen op elkaar hebben.
Rode pijlen → Richting hoe factoren en effecten invloed hebben op andere effecten.

Opdrachtenstencil spiercontractie

Groep: …………

Inleiding
Met behulp van dit opdrachtenstencil leren jullie hoe een impuls vanuit de hersenen leidt tot spiercontractie. Deze opdracht doen jullie in groepjes van twee of drie. De groepjes zijn van tevoren ingedeeld.

Bij deze opdracht hebben jullie je biologie leerboek nodig. Jullie gaan een schema maken dat het proces van de hersenen naar spiercontractie laat zien. Door de vragen te beantwoorden en de opdrachten uit te voeren, maken jullie stap voor stap een schema over spiercontractie.

Opdrachten en vragen
Bij opdracht 1 t/m 7 en vraag 1 t/m 5 hoort de tekst 'Skeletspieren' in bladzijde 158 en 159 van jullie boek. Pak deze leerstof in jullie boek erbij.

Opdracht 1
Wanneer een motorische eenheid een impuls ontvangt van een motorisch neuron, zorgt de motorische eenheid voor de contractie van de spier.
Zet dit proces in het schema met behulp van de kaartjes, zoals in het stencil 'Het maken van een schema' is uitgelegd. Bedenk hierbij eerst wat de hoofdonderdelen en de effecten zijn in dit proces. Er zijn drie hoofdonderdelen en twee effecten.

Vraag 1
Een neuron kan alleen een impuls sturen als aan een bepaalde eis is voldaan. Wat is deze eis? Tip: zie Thema 5, basisstof 4.

Vraag 2
De contractie van een spier kan krachtig zijn, minder krachtig, nog iets minder krachtig, enzovoort. Waar is de sterkte van de spiercontractie van afhankelijk? Noem twee dingen.

Opdracht 2

De antwoorden op vraag 1 en 2 zijn factoren die invloed hebben op de effecten in jullie schema. Plaats de factoren in het schema. Bedenk hierbij op welke effecten de factoren invloed hebben.

Het proces dat jullie nu in het schema zien, kunnen jullie gedetailleerder maken. Een motorische eenheid bestaat namelijk uit meerdere onderdelen.

Vraag 3

Waar bestaat een motorische eenheid uit? Noem drie dingen.

Vraag 4

Hoe leidt een impuls van een motorisch neuron tot het samentrekken van een spier? Beantwoord deze vraag zo gedetailleerd mogelijk, in minstens vier stappen, van het motorisch neuron tot de spier. Gebruik bij het antwoord de onderdelen van een motorische eenheid.

Opdracht 3

Verwerk het antwoord op vraag 4 in het schema. Bedenk wat de hoofdonderdelen zijn en hoe ze invloed op elkaar hebben.

Opdracht 4

Verwerk in het schema met rode pijlen welke effecten invloed hebben op andere effecten.

In het vorige hoofdstuk hebben jullie geleerd over bewuste reacties en reflexen. Wanneer iemand een bewuste beweging wil maken, sturen bewegingscentra in de grote hersenen impulsen naar motorische neuronen via schakelneuronen.

Opdracht 5

Verwerk dit proces in het schema door minstens twee hoofdonderdelen en twee effecten aan het schema toe te voegen.

Vraag 5

Welke factor heeft invloed op het plaatsvinden van dit proces? Tip: de factor staat al in jullie schema.

Opdracht 6

Geef met rode pijlen in het schema aan op welke effecten de factor invloed op heeft.

Opdracht 7

Verwerk in het schema met rode pijlen welke effecten invloed hebben op andere effecten.

Jullie hebt nu een schema gemaakt dat laat zien hoe impulsen uit de hersenen leiden tot het samentrekken van een spier. Dit gaat tot het niveau waarbij jullie de onderdelen van een motorische eenheid laten zien: de motorische eindplaatjes en de spiervezels. Jullie gaan nu zelf het schema uitbreiden met het proces dat in de spiervezels plaatsvindt.

Bij vraag 6 en opdracht 8 hoort de tekst 'Contractie' t/m bladzijde 159 van jullie boek. Pak deze leerstof in jullie boek erbij. Bekijk ook de video die op de ELO staat.

Vraag 6

Wat zijn de hoofdonderdelen van het proces die jullie in de tekst 'Contractie' gelezen hebben en in de video gezien hebben? Het zijn er negen.

Opdracht 8

Verwerk in het schema het proces dat jullie in de tekst 'Contractie' gelezen hebben en in de video gezien hebben. Gebruik hierbij de hoofdonderdelen die jullie bij vraag 6 hebben opgeschreven. Bedenk wat de effecten tussen de hoofdonderdelen zijn. Bedenk welke factoren invloed hebben op effecten en hoe effecten invloed hebben op andere effecten.

Appendix 2 Worksheet Control Class (in Dutch)

Opdrachtenstencil spiercontractie

Groep: …………

Inleiding

Met behulp van dit vragenstencil leren jullie hoe een impuls vanuit de hersenen leidt tot spiercontractie. Deze opdracht doen jullie in groepjes van twee of drie. De groepjes zijn van tevoren ingedeeld. Bij deze opdracht hebben jullie je biologie leerboek nodig.

Vragen

Bij vraag 1 t/m 5 hoort de tekst 'Skeletspieren' in bladzijde 158 en 159 van jullie boek. Pak deze leerstof in jullie boek erbij.

Wanneer een motorische eenheid een impuls ontvangt van een motorisch neuron, zorgt de motorische eenheid voor de contractie van de spier.

Vraag 1

Een neuron kan alleen een impuls sturen als aan een bepaalde eis is voldaan. Wat is deze eis? Tip: zie Thema 5, basisstof 4.

Vraag 2

De contractie van een spier kan krachtig zijn, minder krachtig, nog iets minder krachtig, enzovoort. Waar is de sterkte van de spiercontractie van afhankelijk? Noem twee dingen.

Vraag 3

Waar bestaat een motorische eenheid uit? Noem drie dingen.

Vraag 4

Hoe leidt een impuls van een motorisch neuron tot het samentrekken van een spier? Beantwoord deze vraag zo gedetailleerd mogelijk, in minstens vier stappen, van het motorisch neuron tot de spier. Gebruik bij het antwoord de onderdelen van een motorische eenheid.

In het vorige hoofdstuk hebben jullie geleerd over bewuste reacties en reflexen. Wanneer iemand een bewuste beweging wil maken, sturen bewegingscentra in de grote hersenen impulsen naar motorische neuronen via schakelneuronen.

Vraag 5

Aan welke eis moet voldaan zijn voor het plaatsvinden van dit proces? Tip: jullie hebben het al eerder moeten benoemen.

Jullie hebben nu vragen beantwoord over hoe impulsen uit de hersenen leiden tot het samentrekken van een spier. Dit gaat tot het niveau van de motorische eindplaatjes en de spiervezels. Jullie gaan nu nog dieper in het proces kijken: naar het proces dat in de spiervezels plaatsvindt.

Bij vraag 6 en 7 hoort de tekst 'Contractie' t/m bladzijde 159 van jullie boek. Pak deze leerstof in jullie boek erbij. Bekijk ook de video die op de ELO staat.

Vraag 6

Wat zijn de belangrijke begrippen van het proces die jullie in de tekst 'Contractie' gelezen hebben en in de video gezien hebben? Het zijn er acht.

Vraag 7

Beschrijf in eigen woorden het proces dat jullie in de tekst 'Contractie' gelezen hebben en in de video gezien hebben. Doe dit zo gedetailleerd mogelijk, vanaf het begin tot het eind. Gebruik hierbij de begrippen die jullie bij vraag 6 hebben opgeschreven. Bedenk hoe elk begrip invloed heeft op een ander begrip. Tip: er zit ook een cyclus in het proces.

Appendix 3 Pre- and Posttest (in Dutch)

Vragen spiercontractie

Groep: ……………

De vragen maken jullie in groepen van twee of drie. De groepjes zijn van tevoren ingedeeld.

Vraag 1
Welke drie soorten neuronen zijn er?

Vraag 2
Wat is een impuls?

Vraag 3
Langs welke neuronen gaat een impuls vanuit de hersenen naar een spier?

Vraag 4
Waar bestaat een motorische eenheid uit?

Vraag 5
Uit welke filamenten bestaan de myofibrillen van spiervezels?

Vraag 6a

Op welke filamenten hebben Ca^{2+}-ionen invloed?

Vraag 6b

Wat voor invloed hebben Ca^{2+}-ionen op deze filamenten?

Vraag 7a

Op welke filamenten hebben ATP-moleculen invloed?

Vraag 7b

Wat voor invloed hebben ATP-moleculen op deze filamenten?

Vraag 8

Hoe leidt een impuls vanuit de hersenen tot het samentrekken van de sarcomeren? Beantwoord deze vraag zo gedetailleerd mogelijk. Begin het antwoord bij de hersenen en eindig bij de sarcomeren. Beschrijf het proces in minimaal acht stappen. Gebruik de antwoorden van de vorige vragen als hulpmiddel.

Vraag 9
Myasthenia gravis (MG) is een zeldzame auto-immuunziekte waarbij ernstige spierzwakte optreedt. Bij patiënten met MG binden auto-antilichamen zich aan de acetylcholinereceptoren van zenuwcellen. Hierdoor kan acetylcholine zelf niet meer aan deze receptoren binden. Het resultaat is dat de sarcomeren zich niet samentrekken.

Beschrijf stap voor stap (minimaal 8 stappen) het proces van spiercontractie wanneer acetylcholine zich niet meer aan de receptoren kan binden. Beantwoord deze vraag zo gedetailleerd mogelijk. Begin opnieuw bij de hersenen en eindig bij de sarcomeren.

Appendix 4 Coding Scheme

Phase: **Group:**

Coding student's causal reasoning of the process of muscle contraction					
Interaction pattern Defined as steps in the explanation of the biological process		**Quantitative count**	**Qualitative description (quotations)**	**Interpretation** 1. Do they reason simple linear (A -> B), multiple linear (A -> B -> C …) or cyclic? 2. Which mechanisms are students talking about (which are missing)? 3. Are there gaps in the explanation of each mechanism (what are these gaps)?	**Interrater checks on:** Explains the main mechanisms in the process?
General mechanism explanation. (How does muscle contraction happen?)	Script				Explains the main mechanisms in the process? ☐ YES ☐ NO
	Audio (extra)				
Agents Defined as perceived entities (or factors) utilized to explain the biological process productively		**Quantitative count**	**Qualitative description (quotations)**	**Interpretation** 1. Are the mentioned agents (and their effects) indeed part of the process? 2. Are there agents missing (what agents are missing)?	**Interrater checks on:** Explains the mechanism with enough and with correct agencies?
Agents used to explain the biological process, <u>except</u> any possible additional agent that is only mentioned after probabilistic prompting questions are made.	Script				Explains the mechanism with enough and with correct agencies? ☐ YES ☐ NO
	Audio (extra)				
Probability / influential factors Defined as probabilistic situations / change in agents that could influence the process positively or negatively		**Quantitative count**	**Qualitative description (quotations)**	**Interpretation** 1. What are the influential agents/situations? Are they correct? 2. Is the influential agent/situation just named/guessed or is there also an explanation about how it affects the mechanism? 3. Are there influential agents/situations missing (what is missing)?	**Interrater checks on:** Describes how an influential factor operates in the process?
Examples of questions used regarding probabilistic situation. (e.g. Does this always happen? What effect has … on the process?)	Script				Describes how an influential factor operates in the middle of the process? ☐ YES ☐ NO
	Audio (extra)				