Chapter 3
Involving Teachers in the Design Process of a Teaching and Learning Trajectory to Foster Students' Systems Thinking

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3.1 Introduction

Systems thinking is important in science education to help students make sense of complexity in (biological) systems (Verhoeff et al., 2018). Researchers agree that this higher-order thinking skill can assist students to create a more coherent understanding of biology by seeing the universal principles that apply to biological systems at different biological levels of organization (Hmelo-Silver et al., 2007; Knippels & Waarlo, 2018; Raved & Yarden, 2014; Verhoeff et al., 2008). Nowadays, many curricula include systems thinking (American Association for the Advancement of Science, 1993; Yoon et al., 2018). For example, the American Next Generation Science Standards (NGSS) include the crosscutting concept 'systems and system models' which focuses on defining systems, specifying their boundaries and using models (NRC, 2012). In the Netherlands, systems thinking has been part of the end terms for secondary biology education since 2010 (Boersma et al., 2010). It is described as '*the ability to differentiate between different levels of biological organization, elaborate relationships within and between different levels of biological organization and explain how biological units maintain and develop themselves on different levels of biological organization*' (Boersma et al., 2010, p. 33).

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3.1.1 Definitions of Systems Thinking

While systems thinking has been part of many curricula for some time now, multiple definitions of systems thinking can be found in the science education literature. Ben Zvi Assaraf and Orion (2005) use the Systems Thinking Hierarchical (STH) model to describe the skills systems thinking includes, that is the ability to: (1) identify the system components and processes; (2) identify relationships between separate components and processes; (3) understand the cyclic nature of systems and organize components and place them within a network of relationships and make generalizations; (4) understand the hidden components of the system and the system evolution in time (prediction and retrospection). The National Research Council (NRC, 2012, pp. 63–64) defines systems thinking as '*the ability to understand how an entire system works, how an action, change, or malfunction in one part of the system affects the rest of the system; adopting a 'big picture' perspective on work. It includes judgment and decision-making; system analysis; and systems evaluation as well as abstract reasoning about how the different elements of a work process interact.*' Hmelo-Silver et al. (2017) describe systems thinking in terms of the Components-Mechanisms-Phenomena (CMP) conceptual representation. This representation supports students to think about the components (C) of a particular phenomenon (P) and how they interact to result in a specific mechanism (M) of the phenomenon.

According to Boersma et al. (2011), differences in the definitions of systems thinking can be attributed to the implicit or explicit reference to three systems theories that systems thinking originates from, that is General Systems Theory (GST), Cybernetics and Dynamical Systems Theories (DST). Each systems theory has its own focus and corresponding systems key concepts. GST focuses on the hierarchical structure of open systems and the key concepts are: identity, system boundary, level of biological organization, components and in- and output (Von Bertalanffy, 1968). Cybernetics focuses on self-regulating networks and the key concepts are feedback, self-regulation and equilibrium (Wiener, 1948). DST focuses on the self-organizing component of biological systems and the key concepts are self-organization, emergence, nonlinearity and equilibrium states (Prigogine & Stengers, 1984; Thelen & Smith, 1994). The results of the study of Boersma et al. (2011) showed that most science education studies focused on only some systems concepts in their definition, while they and Verhoeff et al. (2018) recommend to focus on the systems concepts of all three systems theories. The systems concepts can be used as a perspective to explore and analyze complex biological phenomena as biological systems and make predictions about future behavior of a system.

In a previous study (Gilissen et al., 2020a), we investigated how Dutch upper-secondary biology teachers (n = 8) and teacher educators (n = 9) define systems thinking and how they pay attention to systems thinking in their teaching practice. We studied how their definitions and teaching relate to the three systems theories (GST, Cybernetics and DST) and the perspective of current experts, that is systems biologists (n = 7). The following five systems thinking aspects were extracted from the conducted interviews and implicitly refer to one or more systems theories (Table 3.1):

Table 3.1 Overview of the different systems thinking aspects that were extracted from the interviews and related to one or more systems theories, that is General Systems Theory (GST), Cybernetics (C) and Dynamical Systems Theories (DST)

	Systems theories			Indicated aspect as important	
Systems thinking aspects	GST	C	DST	Teacher educators	Teachers
1. Identify the system	x			5/9	7/7
2. Input and output	x	x		8/9	7/7
3. Emergence	x		x	9/9	6/7
4. Development			x	8/9	4/7
5. Modelling	x	x	x	8/9	5/7

This table also gives an overview of the number of participants who indicated a specific aspect as important in the questionnaire. This table is based on Table 2 and 3 of Gilissen et al. (2020a)

1. *Identify the system:* Biological entities can be seen as systems: they can be distinguished from their environment with a boundary and they consist of different interacting components.
2. *Input and output:* Biological systems are open systems; they interact with their environment. Matter, energy and/or information enter the system (input), then the system itself can be seen as a black box where all sorts of processes take place and after that, matter, energy and/or information comes out (output). Dynamic behaviour arises when the input and output of a system changes over time. Moreover, systems are self-regulating. Some of the system components form a control loop. Negative feedback loops tend to reduce disturbances, for example, change in input and positive feedback loops increase the effect of a disturbance in a system. Systems at the level of the cell and the organism converge to a steady state with the aid of negative feedback loops, which is called homeostasis.
3. *Emergence:* The interactions between the components of a (sub)system can lead to appearing of new qualities at a higher organizational level. This phenomenon is called emergence.
4. *Development:* A system develops over time, for example, in terms of developmental biology (how does an individual develop during his life) or in terms of evolution.
5. *Modelling:* Biological systems can be visualized in a quantitative computational or qualitative model to study the system of interest more in detail, for example, to make predictions about the systems behaviour.

All systems biologists indicated the importance of the five systems thinking aspects related to the three systems theories in the questionnaire, which is in line with Boersma et al. (2011) and Verhoeff et al. (2018) who argue that systems thinking comprises the systems concepts of all three systems theories. The teacher educators indicated most of the aspects that are included in the three systems theories as important, while the teachers mostly emphasized the systems concepts of the GST and Cybernetics (Table 3.1). Thus, it seems that the perspectives of teachers and educators are mostly in line with the experts and the systems theories. Despite the teachers and educators emphasizing the importance of systems thinking for biology education, the results showed that systems thinking could receive more attention in Dutch teaching practice. The teacher educators indicated that they paid limited attention to systems thinking in their practice because ‘there is not enough time to extensively elaborate on something complex like systems thinking’. The teachers seem to include systems thinking rarely or only implicitly in their teaching practice because they do not know how to do it. This is a pity because systems thinking can play an important role in creating a coherent overview of biology for students. Systems thinking allows for changing the focus in biology education from an overload of concepts, which are presented in the school textbooks, to a number of key concepts (that is system characteristics) which can be applied and are useful in a wide variety of biological contexts (Verhoeff, 2003). This would even make it possible to save time, because the focus is on understanding the key concepts which are needed to understand biological phenomena in general, instead of on teaching all the different chapters in the school textbooks.

3.1.2 Teaching Systems Thinking

Literature gives several recommendations regarding teaching systems thinking, but there is no ready-to-use pedagogy for teachers to implement systems thinking in biology education yet.

According to Verhoeff et al. (2018), systems thinking can be implemented in education as a metacognitive strategy to understand biology. Systems can be identified in all biological phenomena around us and share universal system characteristics. Based on the systems theoretical concepts of three systems theories described by Boersma et al. (2011) and the systems thinking aspects that are emphasized as important by current systems biologists, seven system characteristics can be identified: systems have a *boundary*, consist of different *interacting components*, have an *input and output*, are regulated by *feedback loops*, are *dynamic* and are *hierarchical* (involve different levels of biological organization) (Gilissen et al., 2020a). Moreover, an overarching characteristic can be identified, that is *emergence*. Systems have emergent properties which are new qualities that emerge from the interactions between the components of the system. For example, collaboration of different organs, for example, muscles and nerves, at the organism level leads to the emergent property of walking.

Taking a systems’ perspective to biology means an understanding of the causes of the *interactions* between the *components* among different *levels of biological organization* that result in *emergent properties*. Students have to be assisted to learn to reason across these different levels when explaining complex biological phenomena (Asshoff et al., 2019; Knippels & Waarlo, 2018). The yo-yo learning and teaching strategy focuses, among others, on the system characteristics *hierarchy* and *interactions* and can be used to foster students thinking between and within these levels (Knippels, 2002; Knippels & Waarlo, 2018). This strategy includes a guided learning dialogue starting with a central question/problem. Causal explanations can be found by moving down to lower levels of biological organization and functional explanations by moving up to higher levels (Knippels & Waarlo, 2018).

Awareness of the universal system characteristics can be helpful to understand biological systems in various contexts: the system characteristics can be used as a perspective or lens to see biology in a more coherent way (Verhoeff et al., 2018). Experts seem to make significantly more explicit references to system characteristics, i.e., apply systems language (Jacobson, 2001) and integrate more dynamic structures, behaviours and functions in their reasoning (Hmelo-Silver et al., 2007). Novices naturally seem to focus more on the perceptually available, static structures of involved subsystems. Therefore, researchers recommend stimulating students' explicit use of the system characteristics during their reasoning (Hmelo-Silver et al., 2007; Jordan et al., 2013; Tripto et al., 2016; Tripto et al., 2018; Westra, 2008; Verhoeff et al., 2008; Verhoeff et al., 2018). Results from the study of Tripto et al. (2016) showed that the use of explicit systems language by teachers encouraged students to make more use of systems language themselves in comparison to a control group.

The National Research Council (2012) emphasizes to teach students to make an explicit model (for example, a schematic drawing) of the system of interest in which the main system *components* and their *interactions* are made visual. A visualization of a system provides a way to understand the system under study and test hypotheses. Modelling qualitatively or quantitatively provides a way to make the invisible visible (Hmelo-Silver et al., 2007). Qualitative modelling approaches focus on representation of systems in a more abstract way showing some system characteristics (Verhoeff et al., 2008) and quantitative modelling approaches focus on the (mathematical) prediction of the system's behaviour (Wilensky & Reisman, 2006). In both modelling approaches, the focus is on identifying the system *components* ('agents') and their *interactions* ('actions'). Verhoeff et al. (2018) recommend qualitative modelling to develop an initial systems concept.

3.1.3 Focus of the Research

The overarching aim of our study is to implement systems thinking in Dutch upper-secondary biology education in a sustainable manner. To bridge the gap between research and educational practice, we involved teachers in our study as *co-designers*. The interplay between researchers, teachers and students makes it possible to go from the intended level (theory about (teaching) systems thinking brought in by the researchers), to the implemented level (design and enactment of the lessons by the teachers), to the attained level (student products and observations provide information about student learning) (Van den Akker, 2006). Another advantage of teachers as co-designers is the chance of good *implementation fidelity* (Sandoval, 2014); because the teachers participate in the design process, they know how the lesson should be taught because they are aware of the underlying principles of the lesson.

In this chapter, we focus on the contributions of teachers during the design process of a learning and teaching strategy on systems thinking and their (learning) experiences.

Lesson Study (LS) was used to design and evaluate lessons on systems thinking in collaboration with teachers. LS is an approach in which a team of teachers collaboratively designs, performs, observes and evaluates a lesson in different steps, the so-called *research lessons* (Fernandez & Yoshida, 2004; Hart et al., 2011; de Vries et al., 2016). These lessons consist of several learning and teaching activities, the so-called *key activities*. An LS team is assisted by a knowledgeable other (in our case *the researchers*) who chairs, prepares and summarizes the meetings of the LS team (Takahashi, 2014). Although, LS originally is known as a teacher professional development approach (Lewis et al., 2006), it is also used nowadays for research purposes (Bakker, 2018, p. 16). While the role of teachers as co-designers has been emphasized by several studies (Cober et al., 2015; Westbroek et al., 2019; Penuel, 2019), it seems that there are no studies that report about the contributions and learning experiences of teachers as co-designers in a research purposed LS approach. Therefore, the following research questions are addressed:

1. *What is the contribution of teachers in the design of a teaching and learning approach in the context of Lesson Study to foster students' systems thinking?*
2. *What do teachers report to have learned from their participation in a Lesson Study trajectory on teaching systems thinking?*

3.2 Method

This chapter reports about two Lesson Study (LS) cycles. Both case studies have been analysed in a qualitative way. Each LS cycle consists of various steps:

- *Design of the lesson*: determine student learning goals, corresponding key activities to achieve these goals and expected behaviour for different types of students that will be observed, the so-called *case students*;
- *Enactment of the designed lesson*: one teacher teaches the lesson, while the other team members observe specific case students to determine students' learning caused by the key activities;
- *Evaluation, improvement and re-enactment of the lesson* in a second class by another teacher. After enactment of the lessons, the observers conducted a short interview (maximum 5 min) with the case students in which they asked what the students think they have learned, what they valued in the lesson and how they think the lesson could be improved. These interviews, the observation notes of the lesson and the student materials are used as input for the evaluation meetings.

The different LS meetings and the enactment of the designed lesson give the opportunity to investigate the contributions and learning experiences of the teachers during the whole process.

3.2.1 Participants

The lessons were designed and evaluated in close collaboration with the three authors of this chapter (from now on called *researchers*) and two secondary biology teachers. The three researchers functioned as *knowledgeable other* (Takahashi, 2014) in the LS team which means that they explained the LS approach to the teachers, introduced the main recommendations from literature, chaired the meetings, worked out the lesson plans in more detail and summarized the meetings. The first researcher has 5 years of experience as a secondary biology teacher and is a colleague of the involved teachers. She was present during the whole LS trajectory, while the second and third author attended a couple of the meetings. Julia (pseudonym) is female, has a background in physiotherapy and has 8 years of experience as a secondary biology teacher. Frans (pseudonym) is male, has a background in tropical forestry and has 10 years of experience as a secondary biology teacher. The school belongs to a school community in the eastern part of the Netherlands and offers senior general secondary education and pre-university education. During the lessons and the evaluation meetings, the LS team was accompanied by an extra observer, which is the second or third author or a staff member of the school. The two lessons were performed in two senior general secondary biology education classes (n = 26, n = 29, 15–16 years old students), lasted 60 min and were performed during school year 2018–2019. For each lesson, three case-students (and three back-up students) were selected to observe in detail. The selection of students for lesson 1 was based on motivation because the teachers did not have test scores yet: case student A represents an obviously motivated and hard-working student, student B represents a quiet but hard-working student, student C represents a passive student. The selection of students for lesson 2 was based on their average scores on a regular biology test: case student A scored especially well on the insight and application questions, student B on the application questions and student C scored high on the factual questions.

3.2.2 LS Meetings

LS 1 consisted of four preparation meetings, the enactment of the first version (1α) and second version (1ß) of the lesson in classroom practice, two meetings in which the taught lessons were discussed and improved and one evaluation meeting. LS 2 consisted of two preparation meetings, the enactment of the first version (2α) and second version (2ß) of the lesson in classroom practice, two meetings in which the taught lessons were discussed and improved and one evaluation meeting. All meetings lasted between 1 and 2 hours, were audio-recorded and summarized. Design choices and challenges (decision points) were highlighted and categorized into the following emerging categories, “teachers’ knowledge of student capabilities”, “teachers’ didactical knowledge”, “teachers’ motives”, “practical concerns of the teachers”, “literature provided by the researchers” and “student observations and products” (Tables 3.2 and 3.3).

Table 3.2 Illustration of the decision points the teachers faced during the development of lesson 1

Decision point	Elucidation	Decision based on
1. Specifying the learning goal of the lesson	At the first meeting, the first researcher introduced the concept of systems thinking to the teachers including the seven system characteristics that students should be made aware of. The teachers discussed what the students exactly should learn about the system characteristics in the first lesson: Frans: "*In short, students must be able to name the seven system characteristics. Should they also be able to describe them? That is the question: to name, describe or explain.*" Julia: "*I think that it would be a nice goal if students are able to recognize and name the different system characteristics of a system after lesson 1.*" Frans: "*I am not sure if that is not too little.*" Julia: "*Description of the system characteristics should be achieved in the upcoming lessons, but for lesson 1 it seems too much.*" Frans: "*For these students formulating is very difficult, while recognizing and learning by heart is easier for them.*"	Teachers' knowledge of student capabilities
2. Way to introduce the system characteristics	The teachers decided to introduce the characteristics explicitly to students because this is recommended by the literature (Hmelo-Silver et al., 2007; Jordan et al., 2013; Tripto et al., 2016, 2018; Westra, 2008).	Literature provided by the researchers
	The teachers think that this group of students will experience difficulties to come up with abstract system characteristics by comparing different biological phenomena (inductive approach), so they choose a deductive approach: Julia: "*Only give the example of the cell, the topic we just taught. First introduce the seven system characteristics in the context of the cell. In follow-up lessons, other examples can be given in which students should find out whether the system characteristics can be applied. I guess that is more in line with the students' level. If I just ask them about the levels of biological organization [hierarchy], they do not know what I'm talking about. […] It would probably be better to start with a system that is more in line with their experience, a mobile phone or the school for example.*"	Teachers' knowledge of student capabilities
	The teachers discussed icons to visualize the different system characteristics. They came up with a tangram as a metaphor for a system (Fig. 3.1a). Moreover, the teachers formulated guiding questions related to each of the system characteristics (Fig. 3.1b). By answering the questions, the students can create an overview of a biological system in terms of the system characteristics. Julia: "*We have to bring the system characteristics into the classroom as a reminder for the students, but also for ourselves [teachers] so we can easily refer to the characteristics.*"	Teachers' didactical knowledge and practical concerns

3. Context in which the system characteristics are introduced	The teachers determined that the system characteristics will be introduced in the context of the school as a system, because this is a simple example and close to the experience world of the students which will possibly lead to more enthusiasm. In the second activity, the students have to apply the characteristics to the cell as a system, because "*at the moment the students are taught about this chapter so it is also more in line with the previous lessons and their prior knowledge. In addition, it immediately let the students experience this topic from a systems perspective.*"	Teachers' knowledge of student capabilities and practical concerns
4. Effectivity of the lesson	During the evaluation of lesson 1, the teachers indicated that they observed that most students were passive during key activity 1 and therefore the teachers decided to explain the system characteristics in the context of the school by themselves, so it is possible to shorten this activity from 25 to 10 min. The remaining time could be used to add an extra activity to the lesson in which students gave feedback on the answers of other students. The feedback activity did not work out as the team hypothesized. Based on the observations, it appeared that students need more specific guidance to give feedback to each other. It also seemed that students are used to there being only one right answer, which does not have to be the case when applying the system characteristics because different examples can be given for each of the characteristics, for example, the cell consists of various feedback loops.	Students observations and student products

Table 3.3 Illustration of the decision points the teachers faced during the development of lesson 2

Decision point	Elucidation	Decision based on
1. Specifying the learning goal of the lesson	The teachers concluded that students are aware of the presence of systems (in biology) and the corresponding system characteristics, but need to practice more. Frans: "*Students need to see more examples of systems to be able to get a deeper understanding of systems*." Moreover, student learning results showed that students often described the characteristics hierarchy, feedback and dynamics from their daily life perspective instead of from a systems perspective, so these characteristics should receive more attention.	Teachers' knowledge of student capabilities (based on student products of lesson 1)
2. Topic/context	Lesson 2 will be enacted in the period when the topic human blood glucose regulation (homeostasis) will be taught. This topic gives good opportunities to pay specific attention to the characteristics feedback and dynamics.	Practical concerns
3. Way to improve student understanding of the characteristics feedback and dynamics	Due to the abstract nature of these characteristics, a modelling activity is embedded, which is recommended by Hmelo-Silver et al. (2007). The teachers came up with a simulation of blood glucose regulation in a role play.	Literature provided by the researchers
4. Way to visualize student thinking	The teachers would like to get a more detailed view on student thinking; therefore, they incorporated teaching and learning activities in which students have to visualize the glucose and hormone levels in a graph and have to explain to each other what happens in the graph. In this way the teachers are able to follow the students' thoughts.	Teachers' didactical knowledge
5. Evaluation of the lesson	After lesson 2α, the team concluded that students' representations of the fluctuations of glucose were not detailed enough, due to the format of the graph on the worksheet. Therefore, they changed the format of the x-axis of the graph in lesson 2ß. Moreover, students seemed to find it difficult to explain the cause of a glucose fluctuation. Therefore, the teachers introduced four different coloured pens in lesson 2ß which represented different causes: intake of food, activity, glucagon and insulin, and which could be used by the students to explain the glucose fluctuations. The results of student products of key activity 3 suggest that most students were able to recognize and describe the characteristics feedback and dynamics in the context of glucose regulation (learning goal 1). The student products of results of key activity 5 showed that students formulated questions which show implicit or explicit references with the system characteristics and mostly related to the characteristics components and input and output (learning goal 2).	Student observations and student products

3.2.3 Designed Lessons

3.2.3.1 Lesson 1

The four different preparation meetings in the LS team led to the design of lesson 1 with the following learning goal: students are able to name, apply and describe the eight system characteristics, that is boundary, components, interactions, input output, feedback, dynamics, hierarchy and emergence. Lesson 1α consisted of three key learning and teaching activities:

1. **Introduction of the system characteristics in a teacher-student conversation in a well-known non-biological context.** After a short general explanation of the characteristics by the teacher with the aid of the tangram and guiding questions (Fig. 3.1), the students applied the system characteristics to the school as a system in a teacher-student conversation. Duration: 25 min.
2. **Application of the system characteristics to a biological context.** Students, in groups of 3 or 4, had to answer the guiding questions related to the different system characteristics in the context of the cell as a system. Duration: 20 min.
3. **Naming and describing the system characteristics.** To determine whether the students achieved the learning goal, the students had to name and describe the characteristics in their own words. Duration: 15 min.

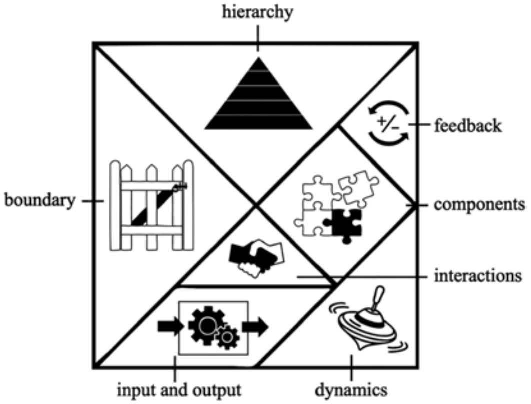
In lesson 1ß key activity 1, the teachers explained the system characteristics in the context of the school themselves (and did not ask the students to do this) which led to a shortening of this activity from 25 to 10 min. In this case, it was possible to add an extra step to activity 2. After answering the guiding questions, the student groups exchanged their answers and gave feedback on the answers of the other group.

3.2.3.2 Lesson 2

Two preparation meetings in the LS team led to the design of lesson 2 with the following learning goals: (1) Students are able to recognize and describe the system characteristics in a new biological context; (2) Students are able to formulate questions related to the system characteristics to identify and unravel an unknown system. Lesson 2α consisted of three key learning and teaching activities:

1. **Visualization of the blood glucose regulation.** In groups of 3 or 4, students had to visualize the glucose regulation of a person over one day with a seesaw in a roleplay. The case student had to draw the fluctuating glucose level in a graph. The other students had to play the role of control centre and the alpha and beta cells in the pancreas. Duration: 20 min.
2. **Explanation of the glucose fluctuations.** The students had to explain why there is an increase or decrease in the glucose level they have drawn in the graph. Duration: 10 min.

A – Tangram



B – Guiding questions

Boundary – Where can you draw a systems boundary? What belongs to the system and what belongs to the environment?

Components –Which components does the system consist of? What is the function of the individual components within the system?

Interactions –What are the relations between the different system components?

Input and output – What (energy, information or matter) enters the system? And what leaves the system?

Feedback – Which feedback loop(s) can be made with the system components?

Does the feedback lead to opposing changes within the system?→negative feedback

Does the feedback lead to enhancing changes within the system?→positive feedback

Dynamics – Which regular changes occur in the input and output? In what way do changes take place within the system over time (hours, days, months, years)?

Hierarchy – In which subsystems (and to which larger system) can you divide the system? And, to which levels of organization does these (sub)systems belong?

Emergence – Which behaviour or properties arise on the systems level caused by the interactions of the system components?

Fig. 3.1 (**a**) presents the tangram which has been used as a metaphor for the different system characteristics that are symbolized with icons. The individual pieces (with different shapes) represent specific system characteristics and together they illustrate the concept of emergence: the different pieces together form a new shape, for example, a bigger square. (**b**) presents the guiding questions related to the different system characteristics which can be used to investigate a specific biological system from a systems perspective

3. **Description of feedback and dynamics.** The students had to describe the system characteristics feedback and dynamics for the context of glucose regulation. Duration: 10 min.
4. **Recognition of dynamics.** The teacher evaluated the different causes of fluctuations in the graph and asked the students: Can you think of another (biological) system which shows dynamic behaviour? Duration: 10 min.
5. **Formulation of questions to unravel system X.** Students had to formulate questions to unravel what system X is and how it works. Duration: 10 min.

In lesson 2ß, the second enactment of the lesson, small adjustments were made to key activity 1 and 2. The format of the graph was adapted: the previous graph represented different moments during the day on the x-axis (for example, breakfast, lunch and so on) and the new graph represented time in hours of the day. Moreover, the students received four different coloured pens which represented different variables: intake of food, activity, glucagon and insulin. The students could make use of the different colours to indicate the cause of an increase or decrease of glucose in the graph.

3.2.4 *Pre- and Post-interviews*

Before and after the LS trajectory individual semi-structured interviews (approximately 60 min) were conducted with the two teachers. The interviews were audio-recorded and transcribed verbatim by the first researcher. The aim of the interviews was to determine teachers' reported learning progression regarding (teaching) systems thinking and their experiences of the LS trajectory. The transcripts of the pre- and post-interviews were analysed with a qualitative bottom-up approach in which the following emerging codes were used to summarize the interviews: "understanding of systems thinking", "teaching systems thinking" and "(expected) (learning) experiences of the LS trajectory" (Table 3.4).

3.3 Results

3.3.1 *RQ1: Contributions of the Teachers*

During the design and evaluation phase of lesson 1, the teachers encountered four main *decision points*: specifying the learning goal of the lesson, the way to introduce the system characteristics, the context in which the system characteristics can be introduced and the effectivity of the lesson (Table 3.2). Teachers used their knowledge of student capabilities to align the learning goal of the lesson to students' initial knowledge situation and to determine possible difficulties to achieve the student learning goal. Teachers used their didactical knowledge to think of a

Table 3.4 Reported learning experiences of the teachers related to (teaching) systems thinking the LS trajectory

Teacher	Pre-interview	Post-interview
Understanding of systems thinking		
Julia	Did not know about systems thinking. She saw systems thinking as the ability to see coherence between different systems: "*It is a skill. When students are trying to answer a question, they stay mostly within one system, but they have to learn that different (sub)systems are working together and they need to involve these systems to answer the question. See the bigger picture*."	Systems thinking has made her think differently about biology: *"I myself gained more insight into systems thinking and also see how this could help the students to think about biology." […] If I approach this from a systems thinking perspective, what is the boundary and what is the input and output, I try to put myself in the student perspective."*
Frans	Knew already about systems thinking from his background in tropical forestry. He described systems thinking as: "*The awareness of systems and their collaboration and how they are organized. The emergent properties are the result of the organization of such a system. […] Each system is born, develops and dies and you find this on each level of biological organization.*"	In retrospection, he thinks that more coherence can be created between the system characteristics. Feedback for example, is already an example of an interaction. The interactions between different components can be a feedback loop. There is also a relation between the boundary and the input and output. The boundary is the place where selection of the input and output takes place.
Teaching systems thinking		
Julia	In her daily classroom practice she paid attention to concept mapping to create conditions for students to learn to connect various systems to see the bigger whole and she paid attention to the different levels of biological organization. She does not use the term 'system'.	Indicated that she thought beforehand it would be easier that students were familiar with the system characteristics. "*For myself, it [the system characteristics] makes so much sense now, so I expected the students to be able to think about them in the same way, but for students it appears less logical and normal.*" She thinks it would be better to introduce the system characteristics already at the start of lower secondary biology education and teach students to look at biology from a systems perspective. Moreover, she experienced students first need to see various examples of systems in biology to which the different characteristics can be applied. She indicates a future LS trajectory could focus on developing a way to let students experience more the utility of the characteristics to understand biology. In her regular lessons she now always tries to pay attention to the system characteristics, for example by asking students which subsystems are involved in a specific question, or what the input and output are.

Frans	In his daily classroom practice he paid attention to the hierarchy of biological systems, the relation between different subsystems, the concept of emergence and the visualization of biological phenomena.	Indicated that he learned that students found it difficult to recognize the system characteristics. He thinks this is due to the abstract nature of the different system characteristics: "*Visualization of the system characteristics, just as simulating the glucose level in a role play, can make it more concrete for students*." He experienced that visualization can improve student understanding, but also can assist them to recognize the applicability of the characteristics more easily in new contexts. In his regular lessons he now pays attention to the system characteristics by trying to motivate students to approach a question from a systems perspective, for example, Which components are involved? How are they interrelated? On which level of biological level of organization are you now reasoning?
(Expected) (learning) experiences LS trajectory		
Julia	Julia expected that involvement in LS will give her more insight into the learning progress of the students during each lesson. She thinks that this will lead to more effective lessons. Moreover, she hopes that the lessons that will be developed around systems thinking will give her enough knowledge/input to integrate it in her own regular lessons as well.	Indicated the LS trajectory as very intensive, but also very informative: "*Lesson Study stimulates to think more deeply about a lesson*." It requires a description of the different student learning goals, the key activities to achieve these goals and expected behaviour of the different case students, which in total led to well thought out lessons. Julia: "*I have never actually looked so much in detail at a lesson*." She indicated that she is proud of the developed lessons. She also indicated that she was a bit scared to perform the lesson "*because you know you are part of a research project, so you want to do it as we discussed it in the meetings*." She indicated that she sometimes felt a bit passive because the first researcher worked out all the details that were discussed in the meetings which led to detailed lesson plans, but she also indicated that she felt very involved in the process.

(continued)

Table 3.4 (continued)

Teacher	Pre-interview	Post-interview
Frans	He expected that LS will give him better insights into how students learn and develop systems thinking. He would like to use this developing knowledge around the use of LS to improve his future lessons.	Frans indicated that he learned a lot from the LS trajectory. "*I did not think there are so many things you would like to discuss in more detail.*" He also indicated that he liked the enthusiasm and the involvement of the first researcher. *"It was nice to see that the expectations we had did come true."* He emphasized the importance of communication between the members of the LS team: *"Does everyone mean the same?"* He thinks this is especially the case for key activities that have an open character, for example, which scaffolds can be given to students when they are working on the key activities. During the meetings it is important to discuss how much and what type of guidance can be given to the students. He ended the interview stating that: "*Participating in this trajectory was very fun and informative, I am glad I participated.*"

way to achieve the learning goal supported with recommendations from the literature provided by the researchers. Practical concerns also influenced the final design of the lesson, for example, connection of the lesson to the regular lessons by using the same biological topic. The teachers seemed to evaluate the lessons based on the student observations and products.

During the design and evaluation phase of lesson 2, the teachers encountered five main decision points: specifying the learning goal of the lesson, the topic/context, the way to improve student understanding of the characteristics feedback and dynamics, the way to visualize student thinking and the effectivity of the lesson (Table 3). Based on student products of lesson 1, teachers developed 'new' knowledge of student capabilities in relation to systems thinking which they used to specify the learning goal of lesson 2. The choice of the topic/context for the lesson was based on practical concerns: how does it fit in the regular lessons? The teachers designed the teaching activities with the use of input from the literature and their own didactical knowledge, and the lesson was evaluated with the use of student observations and products.

3.3.2 *RQ2: Learning Experiences*

Teachers' answers in the pre- and post-interviews were used to determine what they have learned about (teaching) systems thinking and how they experienced the LS trajectory (Table 3.4). Both teachers reported a more sophisticated understanding of systems thinking and biology in general. Moreover, they both indicated they did not expect it should be so difficult to foster students' systems thinking, but they also mentioned new insights and possible ways to achieve students' systems thinking in their future teaching, which new acquired knowledge of student capabilities and didactical knowledge. Based on the interviews, it seemed that the intensive LS trajectory encouraged the teachers to think more in detail about a lesson.

3.4 Conclusion

The first aim of this chapter was to give insight into teachers' contributions during the design process of two lessons to foster students' systems thinking. Analyses of the meetings of the two Lesson Study (LS) cycles (Tables 3.2 and 3.3) show that in both lessons the LS team made decisions about the same major issues, for example, specifying the learning goals, the choice of the key learning and teaching activities and the determination of the effectivity of the lessons (Fig. 3.2). The learning goals of both lessons were specified with the use of teachers' knowledge of student capabilities. The choices for the various key learning and teaching activities were based on recommendations from the literature (which was provided by the researchers), teachers' didactical knowledge and practical concerns, for example, which topic is

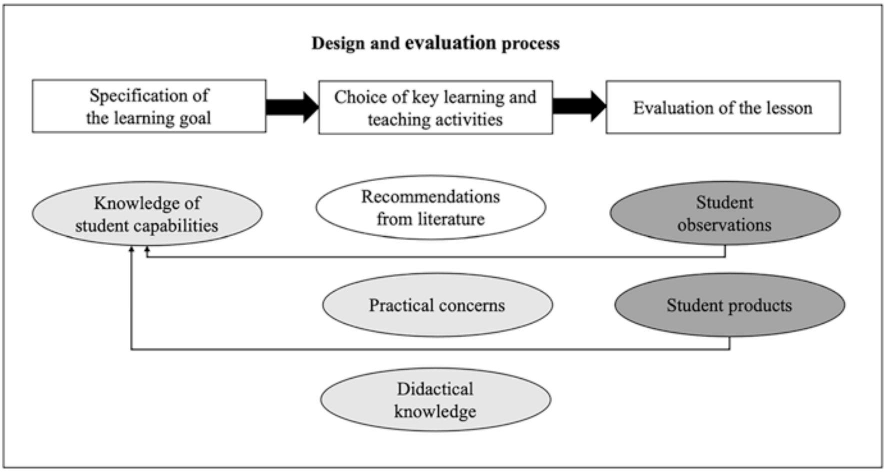


Fig. 3.2 Overview of the different steps in the design and evaluation process. The light grey circles represent the input from the teachers, the white circle the input from literature (provided by the researchers) and the dark grey circles are output of the lessons which gave input to the team to evaluate the effectivity of the lessons

now taught in the regular lessons and how could this be combined in a lesson focused on systems thinking. The evaluation of the lessons, in terms of student learning, was performed with the aid of student products and the observations of the students. Overall, the contributions of the teachers seem to be in terms of their knowledge of student capabilities, didactical knowledge and practical applicability. The main advantage of the involvement of teachers is that the designed lessons are more connected to students' capabilities and daily classroom practice.

The second aim of this chapter was to give insight into the reported learning experiences of the teachers. As the teachers indicated in the post-interview, they learned a lot from the LS trajectory. This was due to the fact that a lesson is discussed in a lot of detail, which is (unfortunately due to time constraints) often not possible for their regular lessons. They indicated LS stimulates them to think more deeply about a lesson in terms of student goals, key learning and teaching activities and expected student behaviour, which led to well thought out lessons. Moreover, this trajectory gave them insight into ways to foster students' systems thinking, but also let them experience the difficulty of fostering such a higher-order thinking skill as systems thinking by students. Both teachers indicate they now have a clear idea on how they would foster students' systems thinking in their regular lessons in the future, for example, early introduction of the system characteristics (for example already in lower secondary biology education) in a well-known biological context and regular repetition of these characteristics and guiding questions in different biological contexts. The question remains how they can let students experience the value of the use of the system characteristics to understand biology in a more coherent way. Frans already suggested to use the system characteristics to solve a complex biological problem. Whether this motivates students to use a systems thinking perspective could be investigated in a future LS trajectory.

Both teachers are very positive about their participation: they learned a lot, felt engaged and are proud about the developed lessons. There are only two points that require some attention. The teachers sometimes felt insecure about their teaching actions. They did not know what to do or say when students were working on an assignment, because they were afraid of influencing the research. A similar result is found by Jansen et al. (2021), which showed that teachers can have the feeling that they have to perform well, because they would otherwise hinder the research. In future studies, it is important to talk about this possible anxiety of teachers and to think of ways to avoid it. In retrospect on our study, it would be of great importance to discuss in detail how much assistance teachers could give to individual students during the activities, for example, which scaffolds can be given. The second point is that teacher 'Julia' indicated that she sometimes felt a bit passive because the first researcher worked out all the details. The researchers opted for this in order to relieve the teachers' workload and thereby prevent their dropping out of the study. Participation in an LS trajectory is time-consuming; all meetings together took approximately 30 hours and teachers in the Netherlands already have a high workload.

LS is known as a teacher professional development approach (Lewis et al., 2006). The results show that the teachers in our study learned to think more in-depth about a lesson design, but also learned how they can implement systems thinking in their daily classroom practice, which is development of 'new' knowledge regarding student capabilities and didactical knowledge. Originally, an LS trajectory starts from questions that teachers struggle with. In this specific case study, we involved teachers to solve a question from the research team: how can we foster students' systems thinking? Fortunately, the pre-interviews showed that the teachers were motivated to participate in this study. They indicated seeing the importance of systems thinking for biology students, but also declared that they did not pay explicit attention to systems thinking in their daily classroom practice. The teachers also indicated that they were proud of the lessons they developed themselves, which shows ownership. We think that enthusiasm at the beginning and ensuring teachers' sense of ownership are important prerequisites for a successful designing process.

Overall, this case study is an example in which teachers and researchers closely collaborated on the design and evaluation of lessons to get insight into how students can be fostered to develop systems thinking. It illustrates how expertise from educational practice can be combined with expertise from educational research and so bridge the gap between education and research. The close involvement of teachers in designing an approach to systems thinking proved to be of great value in leveraging students' capability of dealing with complexity in biology.

When interpreting the conclusions of this chapter, it is important to take into account that this is a qualitative case study in which only two teachers were involved. Despite the small scale of the study, it has shown that LS can be utilised as a useful instrument to bridge the gap between theory-driven research and educational practice. With LS, teachers' knowledge of student capabilities, didactical knowledge and practical applicability can be integrated with theoretical knowledge from the educational research community, but can also lead to the construction of new theoretical knowledge. For example, the LS trajectory also led to heuristics regarding teaching systems thinking in biology education (Gilissen et al., 2020b). These heuristics will form the basis for follow-up studies in which they will be given in the hands of in- and pre-service teachers in the context of professional development activities. The main goal will be to investigate how the LS results can act as a germ for further dissemination of systems thinking in biology education by embedding the resulting heuristics into new teaching activities.

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