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# USING CAUSAL DIAGRAMS TO FOSTER SYSTEMS THINKING IN GEOGRAPHY EDUCATION

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To gain insight into complex sustainability problems and acknowledge complexity is essential and can be achieved by creating an overview of the entire system, including interaction between variables. Therefore, systems thinking is recognized as a vital cognitive skill required to grasp complex global problems. Nevertheless, the implementation of systems thinking into general education, and geography in particular, is sadly limited. Encouraging students to use appropriate tools will probably help them understand systems complexity. A lesson series to foster systems thinking in a Belgian high school geography course was developed and implemented. In this design, produced by researchers in consultation with teachers, students were required to elaborate causal diagrams based on original texts and graphs of complex geographical issues. Causal diagrams are expected to support the development of students' systems thinking ability. The interpretation of the information sources from a geographical, and thus multidimensional perspective, is the core of inquiry-based instruction aimed at fostering systems thinking. By describing the gradual use of causal diagrams as a tool to visually represent given data, this article contributes an example of this scaffolding technique in geography education. In addition to a description of the lesson series itself, we also discuss how decisions in the design process were influenced by theoretical as well as practical aspects of geography education in Flanders (Belgium). Furthermore, first reflections on the implementation are illustrated.

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## INTRODUCTION

### Systems Thinking in Geography

Geography as a discipline and as a course for study deals with problems that are complex. Those problems are often multidimensional because variables from both social sciences and natural sciences need to be integrated. This integration creates a broader view and has long been a tradition in geography. The focus on the spatial patterns of these variables, as well as their evolution over time, has ensured that this perspective creates a framework in which solutions are found through collaboration among many stakeholders. Moreover, the level of complexity will only continue to increase because of the growing globalization that is induced by a rising interconnectedness between people, goods, and culture. This evolution challenges students who are expected to develop insight into these complex problems by combining several elements from different fields, but it also challenges teachers who have to establish a suitable learning environment that makes learning about these complex issues feasible. In the literature, systems thinking is described as a cognitive skill necessary to deal with complex problems. Systems thinking is closely related to the field of system dynamics, and it has been defined in many different ways (Hopper & Stave, 2008; Richmond, 1994; Sweeney & Sterman, 2000). However, Arnold and Wade (2015) compared eight definitions and they found some common elements. More specifically, the emphasis on understanding interconnections, feedback loops, dynamic behavior, and seeing systems in their entirety rather than as different parts often reoccurs. Richmond (1994) argues that the purpose is to think more productively about how to improve the way a system



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works. Despite the advantages claimed by the proponents of systems thinking, its implementation into education has not been wide spread (Plate, 2010). However, in geography courses in Flanders (one of the two main regions in Belgium), the use of systems thinking could be a promising approach when dealing with the aforementioned complex issues. The importance of this perspective also has been recognized in the framework of Education for Sustainable Development, a concept supported by the United Nations (Sleurs, De Smet, & Gaeremynck, 2008). Most sustainability issues are already being dealt with in geography courses. Because of their complexity, it is important not to oversimplify them, but to look at the whole system and the interaction between different variables inside the system. Geography's synthesizing effect with its aim to link social and natural sciences should be at the core of geography courses in high school education. The assumption is that stimulating systems thinking as a skill would be helpful in understanding geographical questions. Thus, a lesson series was designed in which fostering systems thinking is the main challenge. Before describing the lesson series in detail, we briefly analyze causal diagrams as a tool in the design context. Afterwards, we discuss the decisions taken in the design process and report on some first reflections.

### Causal diagrams to foster systems thinking

In this design, causal diagrams, also called causal loop diagrams or causal maps, are used as a tool to foster systems thinking, as well as to visualize and structure information. According to Öllinger et al. (2015), causal diagrams consists of nodes (variables) and arcs (causal connections). A sign added to arcs, usually drawn as arrows, indicates whether the effect is an increase or a decrease. Although empirical research on the effect of causal diagrams in general is rather limited (Öllinger et al., 2015), the theory of and empirical studies about the effect of external representations in general, and concept maps in particular, are promising. Moreover, causal diagrams as a specific kind of concept map, have the potential to help individuals visually organize information, which fosters higher order cognitive processes (Novak & Cañas, 2008; Opgenhaffen, 2015). In Belgium, the goal of high school geography education is for students to gain insight into complex systems by emphasizing the way in which many different variables are related to each other, It is not necessary to focus on how to quantify or to simulate these systems, which is probably better suited in a college or university course. This consideration also influenced the designers' choice for causal diagrams. Furthermore, concentrating on a specific kind of relationship (cause-effect), which differs from concept maps, creates causal diagrams that are in fact conceptual models. Creating these kinds of conceptual models in high school courses can perhaps serve as a first step to learn about quantifiable models in university courses. This also closely relates to the field of system dynamics in which the focus is on model structuring and simulations based on these models (Forrester, 1994).

## ANALYSIS OF THE DESIGN CONTEXT

In Flanders, geography is a compulsory course for most study disciplines, which is taken in the last two years of high school. Generally, students enroll in a 50-minute course each week, except for those in natural science disciplines who have two lessons a week in their last year of high school. Attainment levels are set by the government and are translated into more explicit objectives by school associations. In Table 1, the topics' objectives that are dealt with in the designed lesson series are given for the largest school association in Flanders. The objectives for these particular themes are practically the same for each study discipline. Fostering systems thinking is not explicitly mentioned in this table, but the objectives do aim at understanding connections, albeit in a hidden way.

This particular lesson series was designed as part of broader research examining the possibilities of implementing

| THEME | CURRICULUM OBJECTIVES: STUDENTS CAN… |
|---|---|
| Food supply | **identify** the causes and solutions of unequal food supply and **relate** it to demographic evolutions and differences in prosperity |
| Resources | **relate** the tension between production and consumption of resources or energy with differences in demographic evolutions and welfare |
| Carrying capacity: ecological footprint | use the ecological footprint concept to **demonstrate** the unequal regional pressure on the Earth's carrying capacity and **suggest** sustainable solutions |
| Globalization | i. **understand** , based on an example, that the global relocations of industrial and service activities are part of globalization |
| | ii. **examine**, based on examples, the consequences of globalization from a socio-economical or political point of view |
| International migration | **examine**, based on examples, the push and pull factors of demographic migrations from a socio-economical or political point of view |

**TABLE 1.** A fragment of the curriculum objectives of the compulsory geography course in the largest associations of high schools in Flanders (Vlaams Verbond van het Katholiek Onderwijs, 2004).

| | CONTENT | SYSTEMS THINKING SKILLS ACCORDING TO THE OPERATIONAL DEFINITION | | | | |
|---|---|---|---|---|---|---|
| | THEME | (1a) Identify relevant variables in the given information | (1b) Recognize relations between the different variables | (1c) Assign the nature of the relationship (+ of - ) | (2) Describe relations between the variables in words | (3) Explain the influence on the system, if there is interference within the system |
| Lesson 1 | Food supply | | ● | | ● | |
| Lesson 2 | Food supply | | ● | ● | ● | |
| Lesson 3 | Food supply | | ● | | ● | ● |
| Lesson 4 | Globalization | ● | ● | ● | ● | |
| Lesson 5 | Resources | ● | ● | ● | ● | ● |
| Lesson 6 | Carrying capacity: ecological footprint | | | | ● | ● |
| Lesson 7 | International migration | | ● | ● | ● | |

**TABLE 2.** Overview of the different themes together with the elements in systems thinking and in which lesson they are worked on.

techniques to foster systems thinking in geography classes. In total, twelve teachers from eleven different schools implemented the lesson series and 554 students attending the last two years of high school (age sixteen to eighteen) participated. The different study disciplines and school enrollments contributed greatly to the diversity of students.

In order to create a proper framework for the design process of the lessons and for the broader research, the term 'systems thinking' was further operationalized into a definition that emphasized causal diagrams. A person who is apt at systems thinking should have the following three skills: (1) construct a causal diagram based on information of a given source, which means being able to (1a) identify relevant variables, (1b) recognize relations between different variables, and (1c) assign the nature of these relations (+ or -); (2) describe relations between variables in writing; (3) explain the influence on this system (i.e., if there is interference within a system).

The central design team consisted of four people who all have a vocation in geography education. The main designer and first author developed the ideas behind the design of the lesson series. These ideas were thoroughly discussed with all members of the design team. Two members of the design team include a retired Professor of Geography (a.k.a., the fourth designer) at KU Leuven who is still involved in the teacher training program and a geography lecturer (a.k.a., the third designer) who taught high school geography over twenty years before she joined the teacher training department of Karel de Grote University College. Their background in geography had a large impact on the lesson series because content often took center stage in the design process. Even though the idea of using causal diagrams to demonstrate the complexity of systems was seen as an important element, there were many discussions about which specific content to include in these diagrams.

## OVERVIEW OF THE IMPLEMENTED DESIGN

As Table 2 shows, the lesson series' focus on the different elements of systems thinking varies throughout. During almost every lesson, students actively worked to recognize and describe the relations between variables. Identifying these variables and assigning the nature of their relations is implemented progressively over the course as these tasks are more advanced. During the third lesson, students began to explore the influence that interference within a system can have on the system. The fifth and sixth lessons deal with this more thoroughly. The content itself is based on the requirements given by the schools' educational association, which is based on the attainment levels set by the government.

### An Educational Game as an Introduction (Lesson 1; theme food supply; Skills 1b and 2)

As an introduction to the lesson series, students played an educational game in which they describe the relations between different 'actors' in the food supply system. These actors can be a local farmer, a supermarket, the World Trade Organization, or the Amazon rainforest. This game was invented by Daniel Cauchy (Cauchy & Luntumbue, 2007). Although the game is rather complex, the main idea is that students receive an identity card that explains their role in the food system. All students then describe in their

**FIGURE 1.** Students playing the educational game visualizing connections in the food system.

own words how they, as their persona, are connected with another actor in the food system and why. Each pair is then linked together by a rope. Eventually, all the established connections form a cobweb, symbolizing the food system (see Figure 1). Depending on the time available and the students' level, the teacher encourages students to provide more profound explanations and thus raise awareness about the discrepancy in power from the different actors in the system. This game is an important part of the introductory course, and it was chosen early in the design process. The main designer came across this game while searching online for course material on systems thinking and food supply. After consulting with the second designer it was decided to keep the idea for the following reasons. First, the designers want the students to realize how complex a system can be. The experience this game simulates really makes them see and feel the connections in the system. Secondly, the game involves the entire class, and students have to 'play a role'. This can increase the motivation of the students, which is crucial in the learning process. Thirdly, the game is ideal to begin with because in succeeding classes it can serve as a reference to remind the students about the complexity of systems. It was decided to use only the interactive part of the game. The time allocated to analyzing was reduced, and the follow-up activity was removed. This decision was based on the idea that the other lessons can act as a follow up.

### Drawing Causal Relations in the Food Supply System (Lesson 2—3; theme food supply; Skills 1b, 1c and 2)

In the second lesson, the students' objective is to gain further insight in the food system by creating a causal diagram. In order to limit the complexity, the students work in small groups and focus on a subtopic, which is accompanied by two or three questions. Their causal diagram needed to be used to answer these questions. One part of class focuses on the role of prosperity and demography in the world's food problem. The following questions guided their work: 'What is the influence of population growth on the global food demand?' and 'What influence does the evolution of prosperity have on the global food demand?' Another objective is to focus on the role of agriculture in the world's food problem. Students have to answer the following questions: 'What are the possibilities in agriculture for area expansion and intensification? and 'What are their effects?' Students work with given variables to create a causal diagram. They extract the information that is necessary to establish connections between these variables from articles, charts, and maps (see Figure 2 and 3). Providing questions to guide students in their reasoning process might seem logical; however, the designers only realized guidance would be needed after they had agreed upon the content and the level of complexity students should achieve in causal diagrams. Students would otherwise struggle to find a starting point from which they could start creating their diagram. Therefore, the main and second designer decided to provide one or two central questions to help students determine which diagram would

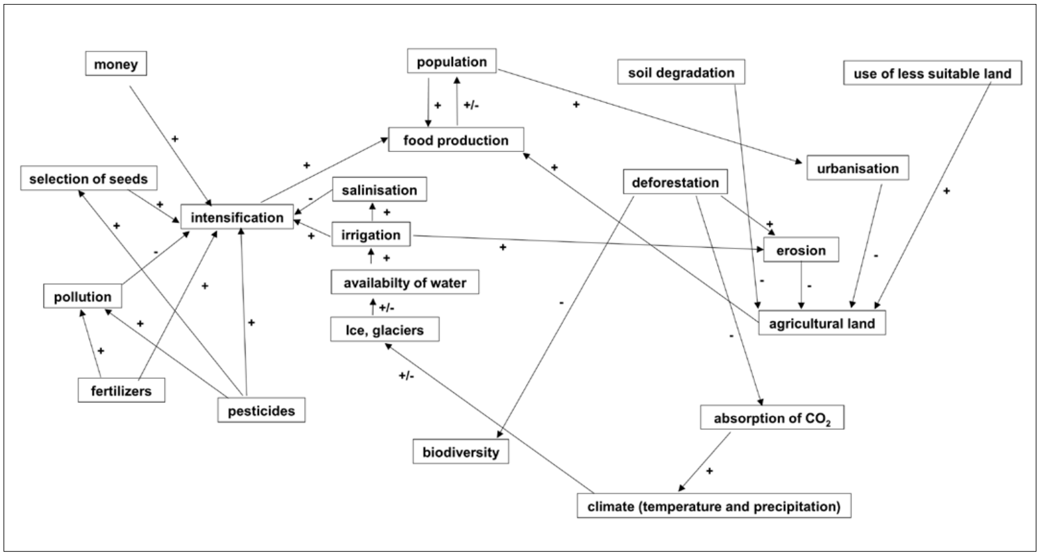


**FIGURE 2.** Digital version of a causal diagram about the food supply that was created by students.

**FIGURE 3.** Students constructing a causal diagram.

be used to answer. Additionally, specific questions were given to students to analyze the articles, charts, and, maps efficiently. The questions, devised by the main designer, evolved during a conversation with the third designer, whose formulations were done meticulously and whose experience as a teacher helped her to anticipate which words would be too difficult for students to answer. After the first trial during the pilot study, the questions developed to analyze the charts, maps, and, texts were specified further. It also was decided to attach these questions to a relating cluster of information to guide the students better instead of providing the questions on the general instruction sheet.

The content of the main questions was based on compulsory curriculum objectives. In an early phase of the design process, there was a third group of students whose questions focused on the role of free trade in the food supply system. The main designer and one of the co-designers wanted to add these questions because they thought it was important to take economic and political variables into account. They thought that variables such as market protection, competition with small farmers, global food market prizes, and speculation would give students a better understanding of the food supply system. While designing the course material, and after consulting with the second and third designer, it was decided not to integrate these questions into group work during the second lesson. Instead, they opted to discuss briefly the main ideas behind free trade during the third lesson. Some of the arguments that came up while discussing this included time constraints, and that the subject of free trade is not specifically mentioned in the curriculum objectives, although the role of agriculture on food demand and the general role of prosperity and demography are mentioned in the curriculum objectives. The difficulties of maintaining a balance between achieving an overview of the entire system and keeping it feasible for students is discussed later in 'reflections on unforeseen obstacles during the design process'.

During group work, the teacher acts as a coach who stimulates the students to read accompanying articles. He or she answers the students' questions, encourages them to explain their reasoning, and challenges them to establish connections between the different sources of information. The students present their developed diagrams in front of class. By explaining the connections in their causal diagram to their fellow students, they further develop a sub-competence 'verbally describing a relation between variables'. The teacher has the opportunity to intervene if a connection is not explained correctly. During the group work stage, the teacher does not always have this option. These short presentations are also important because of the different content each group works on. In the following class session, the teacher shows a synthesis causal diagram to the students in which subtopics are integrated. At first, this synthesis causal diagram can seem complicated to students, but brief tasks are provided so they can familiarize themselves with it. For example, the teacher can ask students where the information from their own causal diagram is situated on the synthesis diagram. Furthermore, actions that have an influence on the system (e.g. increased vegetarianism) are discussed along with variables that would be affected by these actions.

### Identifying Variables in a Documentary About Globalization (Lesson 4; theme globalization; Skills 1a, 1b, 1c and 2)

The fourth lesson starts with an educational conversation about the global expansion of the furniture retailer IKEA. This is dealt with in a more conventional way before students delve deeper into the general causes and effects of globalization. Students watch a documentary and are asked to identify the relevant variables. The teacher guides this activity, and the extracted variables are discussed in class. Afterwards, students categorize whether globalization has an 'increasing' or 'decreasing' effect on these variables. In the final part of the lesson, the variables are used to fill in a pre-structured causal diagram on globalization. With this causal diagram as a basis, students practice describing the relations. During the design process, the first part of this lesson was created after the main part had been designed already. It was decided to use the short documentary on globalization to help students make a causal diagram. The documentary lacks concrete examples, though, and so the main designer came up with two different kinds of introductions that would attract students' attention. The first idea was to play a song about globalization in which advantages and disadvantages of globalization are described. The second designer had reservations about this idea because the advanced English used in the lyrics would have made it difficult for students to understand and discuss. The second idea was to start a student discussion about the evolution of a multinational company. This had greater appeal because students find it easier to relate to a company they know. The designers came up with the following multinationals: Bekaert, the Coca Cola Company, the recent closure of a Ford plant near Genk (a city in Belgium), and IKEA. There was enough information available for all the companies mentioned, except for Bekaert. After a discussion between the first and second designer, they chose not to use the Coca Cola Company as an example because it is already used often in lessons. The closure of the Ford plant was not used either both because by the time the lesson series would be implemented, this would be yesterday's news, and it might only be of interest to students who live near the plant. IKEA was chosen because it is well known among students, enough information is available, and it has rarely been used in lessons before.

### Creating a Causal Diagram About Coltan Mining from Scratch (Lesson 5; theme resources; Skills 1a, 1b, 1c, 2 and 3)

The structure of this lesson is quite similar to the previous one. Smartphones are chosen as a starting point to concretize the general topic 'resources'. Students discuss which are the main resources used to manufacture a smartphone, and they use a map to find out the origin of these resources. In the second part of the lesson, they focus on the specific problem of coltan mining in The Democratic Republic of Congo (DRC). Coltan is a valuable ore used to produce a smartphone's microchip, but its extraction in the DRC is a source of environmental and social problems. Some coltan mines are used by local factions to finance an ongoing war. As a consequence, there is increased migration, a loss of biodiversity, and a decrease in tourism. This issue is explained in a documentary. Students watch this documentary in class and identify the relevant variables individually. Afterwards, a selection of these variables is discussed in class. Once the entire class agrees on the role of these variables, students draw a causal diagram individually, without a pre-structured design. Students finish class with a discussion, which is moderated by their teacher. Their causal diagrams are a starting point for the discussion as it focuses on what specific measures would be helpful to solve (part of) the coltan mining problem. It is important that the teacher stimulates students to explain why the proposed solutions would be effective and which variables and connections would be influenced. The choice for resources that are used in smartphones as a main theme in this lesson seemed rather obvious because it is attractive to students. Documentaries and other useful materials about this topic are also easily available. The main designer once wrote a paper on the problems of coltan mining in the DRC. Therefore, she was aware of the problem's complexity and its suitability to analyze it as a system.

### Discussing the Effect of Interference Within a System (Lesson 6; theme: carrying capacity; Skills 2 and 3)

In the sixth lesson, Earth's carrying capacity is the main topic. As an introduction, students are confronted with a newspaper article about our ecological footprint. For example, how much square feet is needed to produce one slice of bread? After this introduction, students are asked to compare two maps with the aim to find a correlation between the ecological footprint of different countries and their human

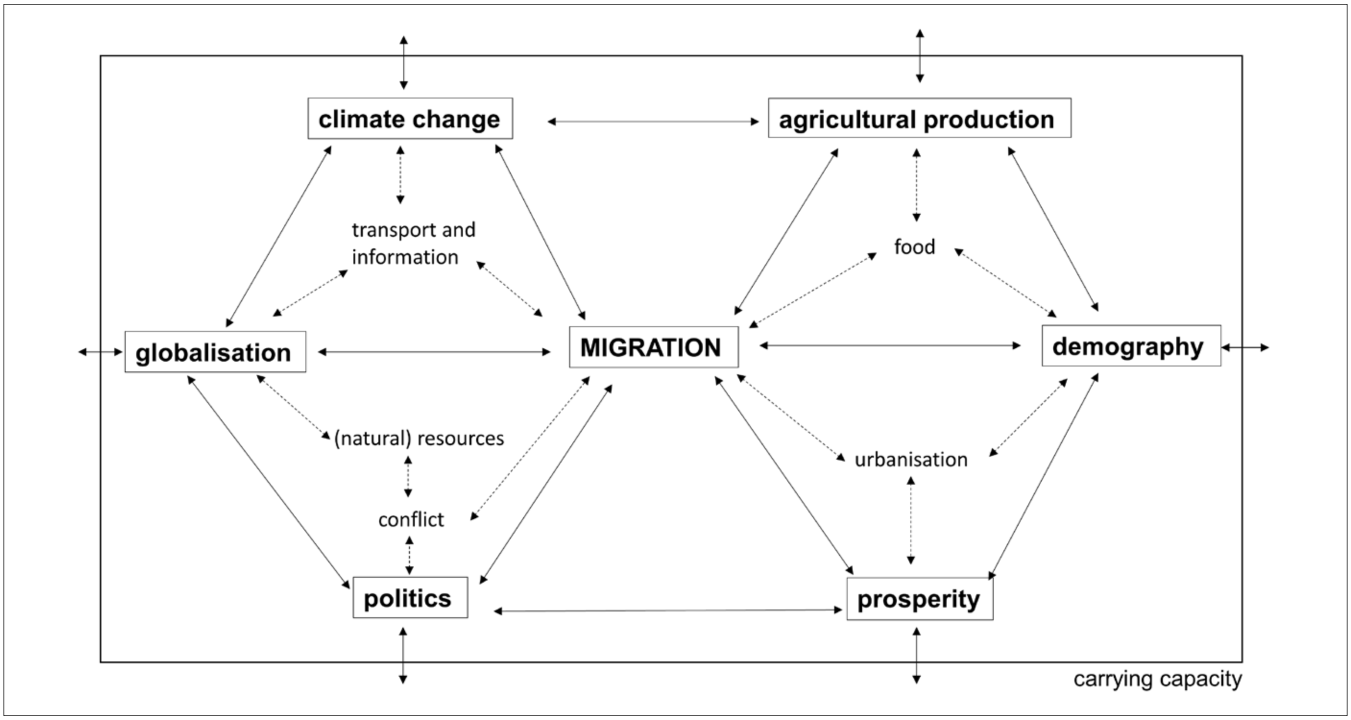


**FIGURE 4.** The abstract synthesizing diagram used in the last lesson.

development index. At this point, the teacher explains the concepts of sustainability and a sustainable lifestyle (triple P concept: people, planet, profit). In the second part of class, students apply these new concepts to focus on the effects of interference within the system of planet earth. They are challenged to devise actions that will foster a sustainable policy and a sustainable lifestyle. First, they are asked to search for actions that would have a decreasing effect on sustainability. Once found, they invert them into sustainable actions. By going through this process, students have to describe why the first action would be unsustainable and what the negative effects would have on Earth's system.

### Combining Diagrams as a Synthesis (Lesson 7; theme international migration; Skills 1b, 1c and 2)

The final lesson deals with international migration. The teacher gives an overview of spatial migration patterns and describes, while interacting with students, the main international migration flows. This topic is used as a synthesis to integrate all former topics. To make this possible, the teacher introduces a more abstract diagram (see Figure 4) to serve as a framework in which students situate smaller causal diagrams about subtopics. Students pair up to draw these small causal diagrams based on information in accompanying articles. After a long discussion on how to integrate the different topics that had been handled over the course into the last lesson, it was decided to use migration, which had synthesized all previous topics. This process is explained in detail later.

## COURSE DESIGN

Despite the clear objective to foster insights in systems and in geographical relations in general, the design of the lesson series was less straightforward. Decisions in the design process were influenced by several theoretical and practical aspects of geography education.

### A Cyclic Development Process

In order to create a feasible lesson series for a current geography course in high school, a user-centered design was used. The key principle behind this is that the design process is influenced by end-users (Abras, Maloney-Krichmar, & Preece, 2004). This approach enabled the designers to take the view of the users (the teachers) into account and the practical limitations they faced. The teachers, as users of the lesson series, were involved in the design process, but the designers and teachers beheld the students as the actual end-users because they felt their purpose was to influence student thinking. To adhere to both the teachers' view and practical limitations, teachers were actively involved in several stages of development. This was achieved by creating two learning communities, which consisted of designers and teachers. All of their meetings were videotaped. The development process was cyclic and followed the phases from action research. However, teachers did not carry out all phases themselves. They actively participated in the 'reflect', 'plan', and 'act' phases, but the lessons were mainly developed by the designers, and one of the designers also led the meetings. Each phase is described in Table 3 and visualized on a time scale in Figure 5.

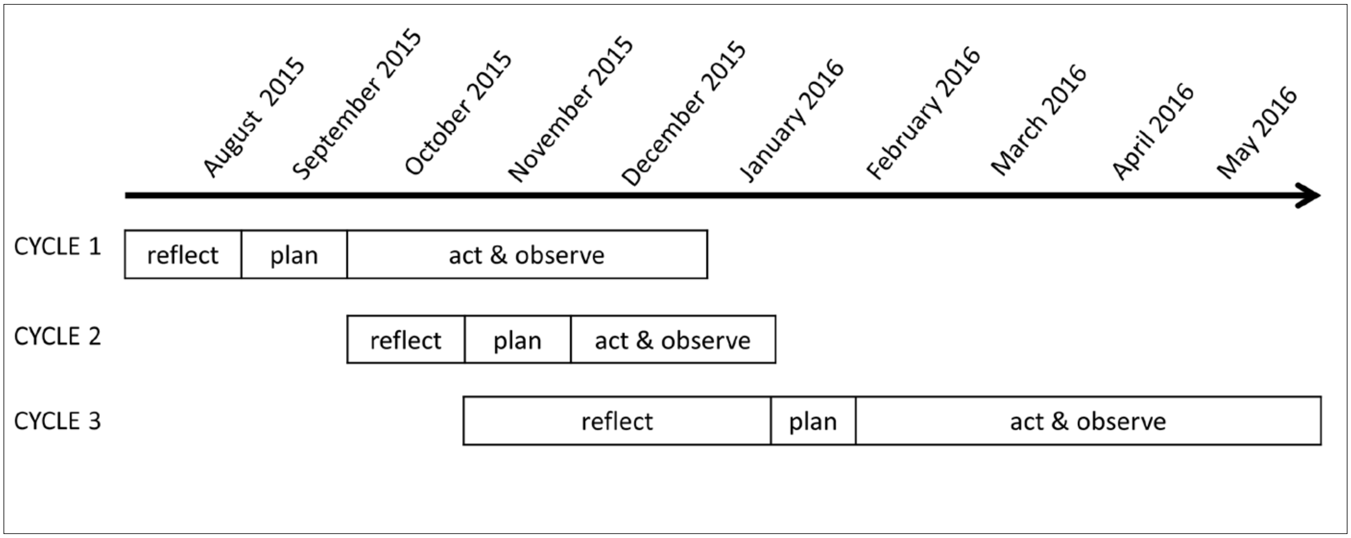


**FIGURE 5.** Time scale of the design process.

| | | |
|---|---|---|
| CYCLE 1 | **REFLECT** | Explorative interviews and observations from which it became clear that teachers in Flanders not really foster systems thinking in their classes. |
| | **PLAN** | First draft of lesson series with help of three experts |
| | **ACT** | Implementation in first pilot study |
| | **OBSERVE** | Observations during first pilot study and conversations with the teacher |
| CYCLE 2 | **REFLECT** | Reflection after first pilot study and conversations in learning communities |
| | **PLAN** | Adjustment course materials |
| | **ACT** | Partly implementation in second pilot study |
| | **OBSERVE** | Observations during second pilot study and conversations with the teacher |
| CYCLE 3 | **REFLECT** | Conversations in learning communities |
| | **PLAN** | Small adjustments of the course materials |
| | **ACT** | Implementation in the experimental group of the study (> 500 pupils) |
| | **OBSERVE** | Observations during the lessons |

**TABLE 3.** Overview of the cyclic development process.

In the first cycle of development, during the reflect-phase, explorative interviews and observations in geography classes revealed a lack of classroom activities to foster systems thinking. It served as a trigger for further research, and eventually, it led to the plan-phase in which a first draft of the lesson series was developed and discussed with three experts. One teacher implemented these course materials in the first pilot study. Practically all of these courses were observed by a designer, and a brief discussion was held after each class. During these discussions, an observer and a teacher reflected on the lesson. A few examples of what was discussed are the teachers' experiences during the lesson, the way students reacted to certain instructions, and the time pressure felt by the teacher and students. Specific ameliorations to the design also were proposed, either to how an instructional unit was defined or to the sequence of instructions and exercises.

Subsequently, the 'observe'-phase and the 'act'-phase were carried out simultaneously. The second cycle of development started with reflecting on the try out. A meeting with the learning communities also was held for the first time to discuss the course material, which had been adjusted based on the findings of the pilot study. After further adjustment of the course material, the lessons were partially implemented in a second pilot study. As not all lessons could be observed, the designers conferred with the teacher (face to face, but sometimes also by telephone) to discuss and reflect on findings. Throughout the third cycle, the designers held more meetings with the learning communities. This made it possible to discuss thoroughly the course materials before their implementation in the study's experimental group. During and after this phase, at least one teacher from each class was observed and two more meetings were held to reflect and to evaluate the lesson series. The designers were convinced that involving teachers in the design process helped these teachers to prepare for the actual lessons. It familiarized them with the use of causal diagrams and with methods to activate students in general. Teachers also were reassured because they had a say in how instructions were formulated, in the complexity of texts (which was a specific concern for teachers with many non-native Dutch speaking students), and they had a platform to discuss problems they would face. One common challenge teachers faced is that there often is more than one right answer. There were

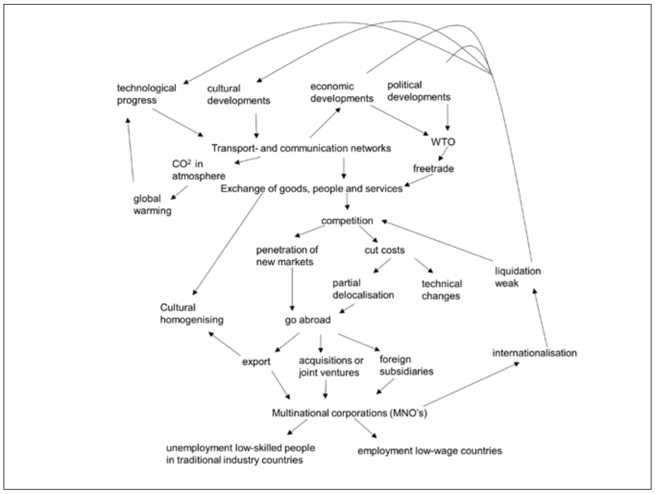


**FIGURE 6.** An early version of the diagram on globalization.

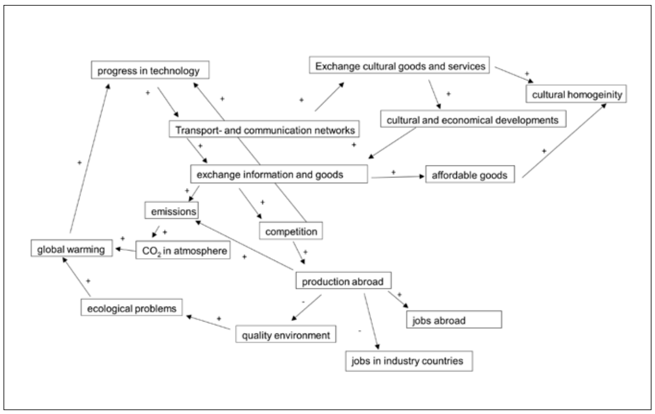


**FIGURE 8.** An evolved version of the diagram on globalization.

frequent discussions among teachers about how to handle this. Another element that was discussed often among teachers was assessing students' knowledge of the course material. In Flanders, teachers have to design their own tests and exams because there are no standardized exams.

## The Didactical Approach Concerning Causal Diagrams

The most important decision in the design process was to implement the use of causal diagrams in each lesson. The use of concept maps and other, related teaching activities has gained popularity in geography classes thanks to the books *Thinking Through Geography* (Leat, 1998) and *More Thinking Through Geography* (Nichols & Kinninment, 2001) in which several detailed, pre-made exercises are given. Research in the Netherlands revealed that teachers do use these exercises (Hooghuis, van der Schee, van der Velde, Imants, & Volman, 2014), but studies also show the importance of improving pedagogy while applying these teaching strategies. Thus, students will not only be motivated and challenged, but they also will achieve higher order thinking skills (Jeong, 2014; Karkdijk, van der Schee, & Admiraal, 2013). Therefore important decisions had to be taken in the design

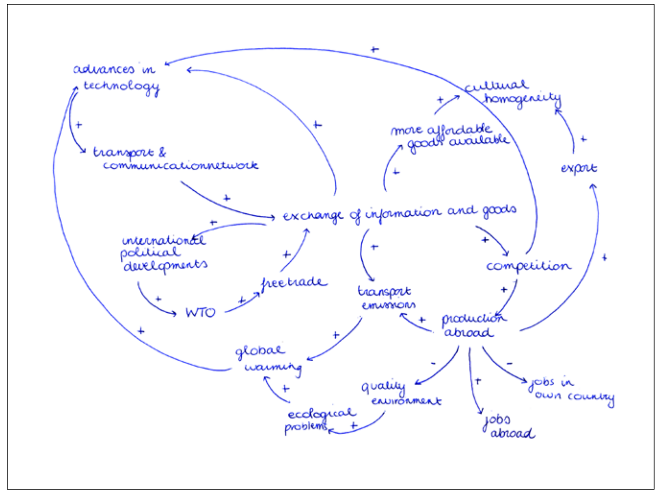


**FIGURE 7.** A drawn version of the diagram on globalization. It was made after the diagram in Figure 6 did not satisfy the main and second designer, because it looked too linear. The feedback loops are not shown clearly.

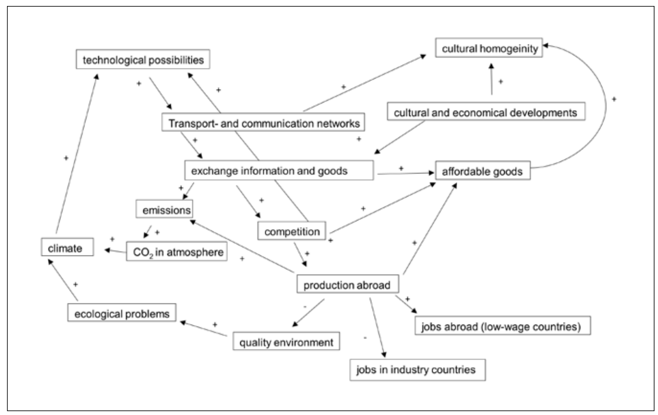


**FIGURE 9.** The final version of the diagram on globalization. Only small changes were implemented in comparison with Figure 8.

process for the way causal diagrams would be used in class. Five of these decisions are explained below.

First, the use of specific software, computers, or tablets was ruled out because of practical limitations in schools, and so the designers opted for pencil and paper. A participating teacher's quote clearly illustrates the need to overcome these practical inconveniences, "I would like to participate in the project, but I hope we won't need computers or technical equipment, because those are always difficult to acquire."

The choice for pencil and paper also accommodated a second decision. The designers elected to stimulate student collaboration and work with group discussions with three to four students. Research on causal diagrams and similar strategies in management shows the importance of constructing causal diagrams in group etc. (Scavarda, Bouzdine-Chameeva, Goldstein, Hays, & Hill, 2006). The amount of information, which students have to process in order to understand the connections in a system, also swayed the designers to opt for teamwork in the lesson series. Although working in groups of three or four students is ideal to discuss numerous sources of information, time constraints required a mitigation of this concept. Conversations in the learning community with experienced teachers contributed to gain insight on the timing of different tasks. Thus, the designers implemented to work in pairs, and they limited the sources of information.

A third decision was choosing a gradual approach, regarding the amount of support offered. Recent studies on the teaching of simulation models show that novice students need sufficient support to enhance the quality of the models they create. The developed model's quality has great influence on knowledge gains (Mulder, Lazonder, & de Jong, 2015). Research on the educational effects of concept maps brings forth the positive effects of scaffolding via the use of an outlined map or given variables (Chang, Sung, & Chen, 2002; Opgenhaffen, 2015). These findings were incorporated in the course materials by utilizing scaffolding twice (i.e., the construction of the causal diagram and the information that had to be processed to construct the diagram). The designers' ambition to enhance the use of the available time, the variation in activities to optimize the students' motivation, and the use of available information sources contributed to the specific translation of this gradual approach. In the discipline of constructing causal diagrams, students evolve throughout the lesson series. They start out by constructing one on a pre-structured diagram and from a given list of variables, and by the final lesson, they should be capable of creating a causal diagram from scratch. Concerning the provided information, students are initially given charts and texts that clearly outline the relations that influence the food problem. During the lesson series, students evolve towards retrieving the variables from documentaries themselves. They watch one in which the relations that refer to globalization are explained in a rather explicit way, and one in which the relations regarding the topic of resources are explained more implicitly.

A fourth choice was to create synthesis phases in which students are able to summarize and reflect upon each topic. The designers thought it would be important to reserve enough time for students to have valuable discussions and to analyze the causal diagrams they developed. The pilot study revealed that students experience difficulties with properly describing the relations they see, mostly because they are not used to it. A teacher described this as follows, "The goal is for students to learn how to use a causal diagram as a kind of framework. They should also be able to explain the relationships. We spent a considerable amount of time on explaining how things are connected. We do this step by step; until we sense that students understand these connections." This feedback triggered the designers to add a cartoon and a few questions that stimulate students to reflect on the relations. The final class meeting incorporates all topics, and students develop one more abstract scheme.

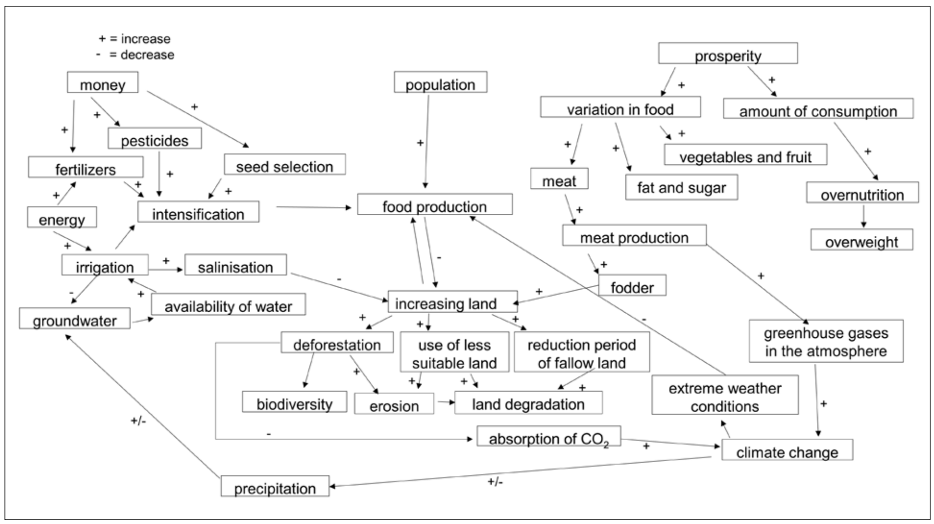


**FIGURE 10.** An early version of the synthesis causal diagram on the world food problem.

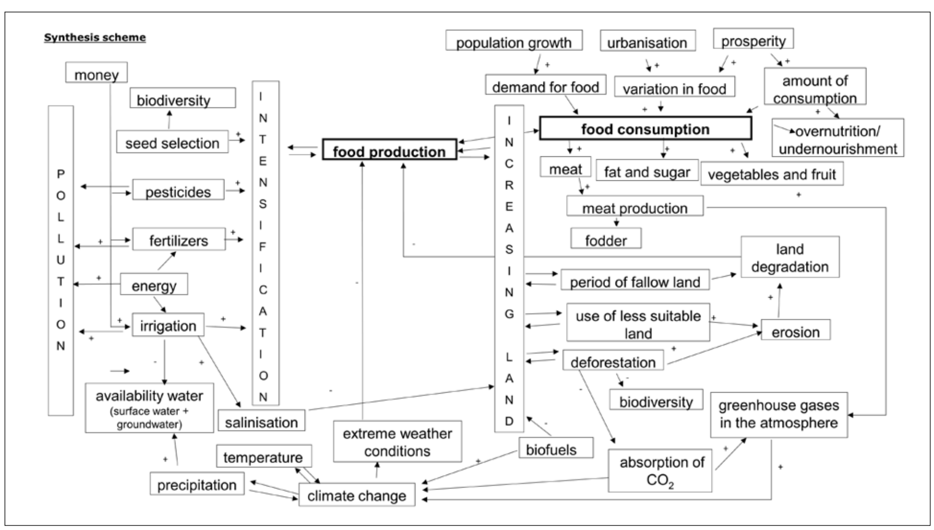


**FIGURE 11.** An evolved version of the diagram on the world food problem. The chaotic appearance of the diagram in Figure 10 triggered the designers to experiment with vertical lay-out and words in bold.

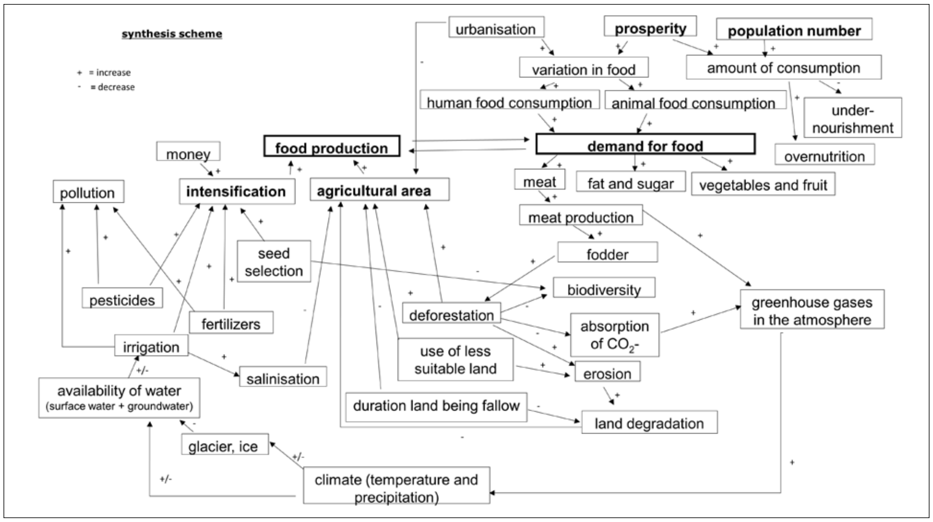


**FIGURE 12.** The final version of the synthesis causal diagram on the world food problem. The second and third designer thought the vertical lay-out in Figure 11 was too chaotic for students. It was changed again, but the words in bold were retained.

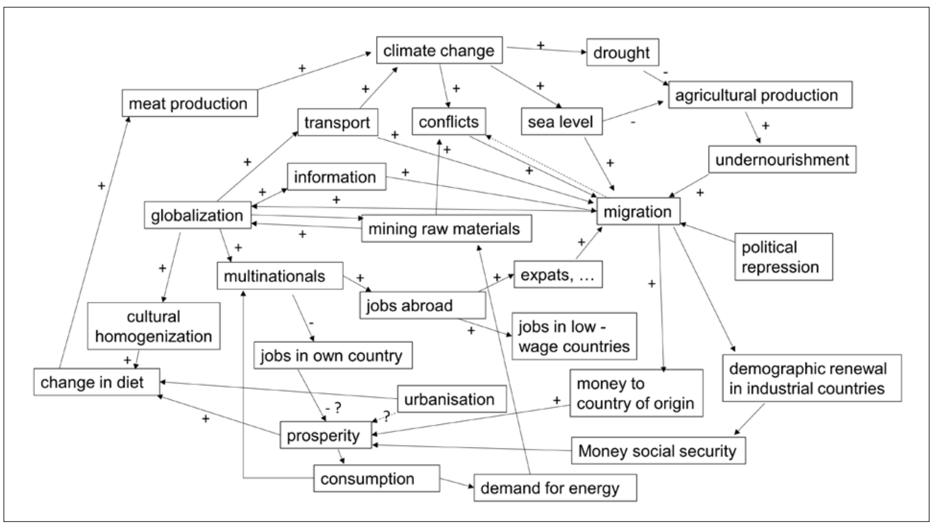


**FIGURE 13.** An early version of the synthesis causal diagram of the entire lesson series.

Causal diagrams play a major role in each lesson, and so defining their content was the first challenge faced. Before instructions for students were created, the main designer tried to construct a causal diagram herself. She experienced several difficulties during this construction phase. Prior to constructing the diagram, proper background information had to be found to form an understanding of the entire system. Despite being a geographer versed in parts of the content, it was challenging for her to find the correct information. In research, cases often are described on a regional level, but in a geography course, students have to see patterns on a global level as well (see also below). Consulting the fourth designer, a retired professor in geography, helped to better understand entire systems. Once the designers became proficient in understanding systems, another challenge emerged. The design team had to decide on the causal diagrams' level of complexity. Questions were raised often regarding the number of variables, the connections, and the system's border. These questions were answered during a continuous process during which the diagrams evolved. Once the team had agreed upon the content of the diagrams, their focus shifted to their spatial organization. They wanted to construct a diagram that would show the complexity of the systems without being too difficult for students to comprehend. Figures 6 through 9 show the evolution in design of the synthesis diagram concerning globalization. This is the first topic for which the main designer created a causal diagram. The first version of it (see Figure 6) was made early in the design phase, before the designers decided to focus on causal diagrams.

Figures 10 through 12 show the evolution of the synthesis causal diagram on the world food problem. The diagram's abundance of variables hindered their spatial organization, which caused it to be unclear to students. The designers therefore experimented with the layout. They added some vertical elements and emphasized important variables that return in the students' research questions by showing them in bold.

The fifth aspect focused on the language used in the written instructions for student use. After this was discussed with teachers in the learning community, some of the instructions were formulated differently. In many cases, the instructions were further operationalized in order to clarify the students' task.

## REFLECTIONS ON UNFORESEEN OBSTACLES DURING THE DESIGN PROCESS

During the design process, the designers faced several unforeseen obstacles. The specific decisions of each lesson were described above in the lesson series' overview. In this section, the difficulties experienced during the design of the entire lesson series are explained.

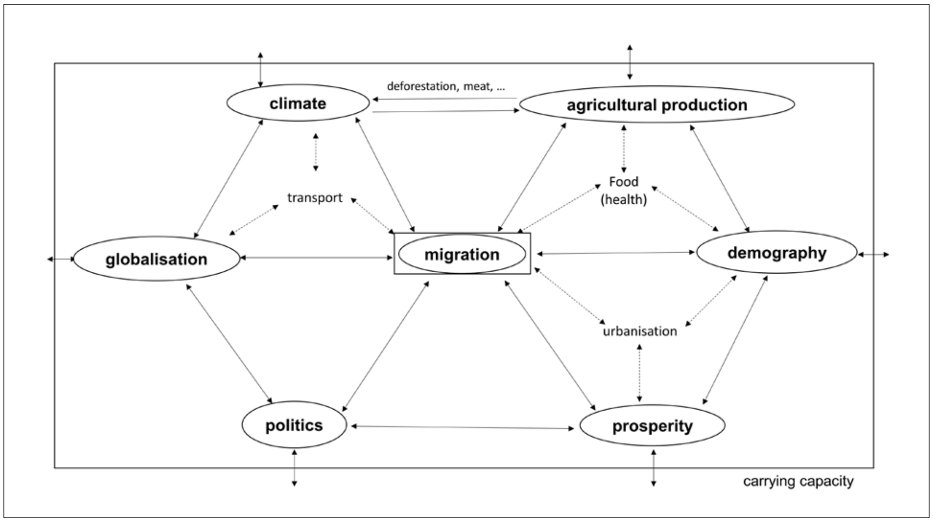


**FIGURE 14.** An evolved version of the synthesis diagram drawn by the second designer in an attempt to create a better overview than the diagram in Figure 13.

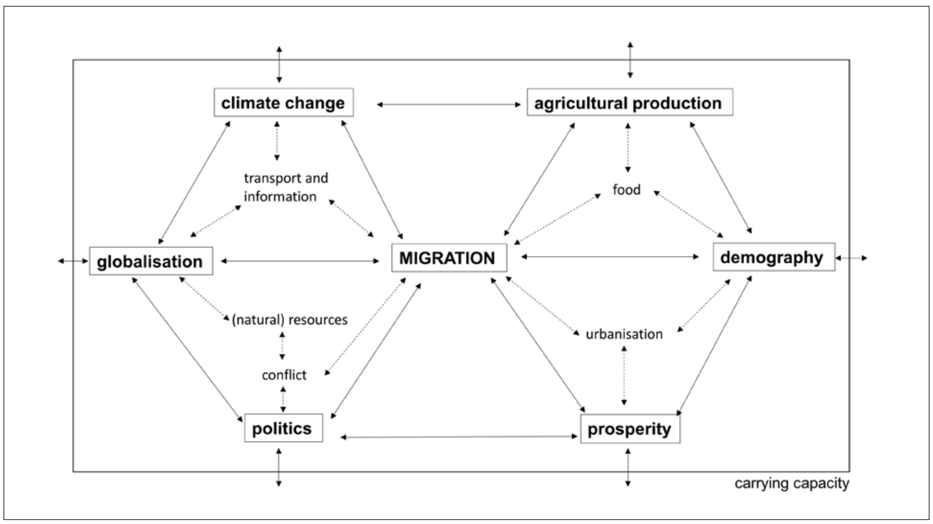


**FIGURE 15.** The final version of the synthesis diagram. After consulting the main designer, small changes were made to the diagram in Figure 13.

A second obstacle arose once the team had finished designing the causal diagrams. The main designer struggled to find appropriate information (e.g., articles, maps, and charts) for students to reason about and to discover connections we wanted them to see. Most articles were too long or not from a neutral point of view. Some figures were discussed with the fourth designer who suggested removing some misleading figures. During a discussion with the third designer, it was decided to write some articles to make sure students could find the necessary connections in the provided information. It was difficult to find a balance as the design team also recognized the importance of making students competent in extracting information from authentic sources that might be biased. Considering available time and the format of group work, it was necessary to provide information in an efficient way.

A third obstacle during the design process was how to integrate different themes. The main designer wanted to develop a lesson series in which all themes were integrated in one large system and taught through a comprehensible case study. It proved to be difficult to find an interesting case study that allowed seeing things on a global scale. The idea emerged to find a main theme in the lessons and to add an extra lesson in which a synthesis could be made based on this theme. One of the ideas for a main theme was the educational game played in the first lesson. If it would have been possible to create a causal diagram with the identities present in the game along with the variables in other lessons, then from each lesson, pieces could have been added to the diagram. In the synthesis lesson, students would then discuss the complete diagram. It proved that the causal diagram would become too complex, and that it would be too difficult to integrate variables directly, for example, from the lesson about coltan mining. An extra synthesis lesson would also be difficult because of time constraints. The third designer proposed migration as a main theme as it allowed synthesizing all lessons. The main designer realized this theme would not require an extra lesson and it would create a broader synthesis at the end of the lesson series. To execute this idea, a causal diagram was made by the main designer with many variables from earlier diagrams. It was difficult to get an overview of the entire system from this new causal diagram and the main connections were not clear either as it was too convoluted. The second designer used this convoluted diagram to create a more abstract diagram in which more generic terms were used. The specific characteristics of a causal diagram were not used which made it possible to have a clear view on the entire system. The diagram was slightly adjusted after consulting the main designer. This evolution is shown in Figures 13 to 15.

Fourth, the designers were fearful that a repetition of causal diagrams would have a demotivating effect on students. To anticipate this potential problem, the designers used diverse information sources and various formats like group work without sacrificing causal diagrams as a central element in most lessons. The different introduction of each lesson and the educational game in the first lesson should also work to motivate students.

A fifth and last obstacle was that compromises had to be made continuously between time available and a wide array of curriculum objectives. Teachers often complained about this problem, but it was encountered even more when methods were developed that required time for discussions among students. Therefore, as described in the overview of the implemented lesson series, the methods were sometimes slightly adjusted in order to be feasible within the available time. For example, the discussions were sometimes in-group, but often also in pairs or with the whole class group together. This made it easier and faster for the teacher to moderate.

## REFLECTIONS ON THE DESIGN'S IMPLEMENTATION

The design's implementation was helpful to gain insight on two challenges that the use of causal diagrams pose. First, a few reflections on the implementation of causal diagrams in the lesson series are discussed. Second, the specific challenges posed by the use of causal diagrams in geography are elaborated on.

### Reflections on the Implementation of Causal Diagrams

Reflections on the implementation of the designed lesson series are drawn from conversations in the learning community on the one hand and from class observations on the other hand. Positive remarks as well as negative ones were made. Most teachers pointed out a comprehensive improvement in students' depth of reasoning. Particularly the exercise in the second lesson, in which students had to develop a causal diagram in groups with given variables and information sources, was mentioned as very interesting. Several teachers enjoyed watching students discuss, as one teacher illustrated. "The first time they had to construct a causal diagram about the food system was truly fascinating to observe. Students were constantly discussing the correct place of variables and arrows. It was a pleasure to behold." However, a few teachers mentioned they encountered problems with the excessive size of some articles and with students struggling to understand connections in charts. During observations, the need for extra guidance was noticed in some groups. A few teachers also bemoaned that there was not enough time to execute all the different activities and the importance of language proficiency in the discussion and synthesis phases. One teacher said: 'Some groups struggled to complete the causal diagram in one hour. They also endured difficulties understanding textual information sources." In schools where a significant part of the students are not native Dutch speakers, the activities' execution took longer. In schools where a prevalent part of the students are native Dutch speakers, teachers had to listen carefully in order to point out inaccuracies when students were describing connections. In traditional Flemish high schools, students are not often required to describe complex connections and conclusions.

Furthermore, teachers and students alike struggled with assessments. Students were told to focus on constructing causal diagrams based on sources of information and to understand the developed schemes instead of learning them by heart. However, according to the teachers, some students experienced difficulties with this. In some schools, students are still used to being quizzed in a rather reproductive way. The teachers also struggled with implementing a different form of assessment. They wondered what kind of questions can be asked on summative assessments or whether it would be a good idea to put more emphasis on giving students feedback. These concerns were sometimes reinforced by the schools as they require a certain amount of quantifiable assessments. Even though these obstacles are clearly part of a larger problem concerning the assessment culture in education, it was helpful to converse with the learning community to partially overcome these issues.

### Reflections on the Challenges Posed by the Use of Causal Diagrams in Geography

Causal diagrams in their current form lack the option to include spatial scales and time scales, which makes it rather challenging to implement them into a geography course. Teachers mentioned an insufficient use of maps during some classes. In addition, a remarkable lack of attention to spatial patterns and embeddedness was noticed during class observations. After several conversations within the learning communities and experts in geography education, it became clear that this problem is multidimensional.

First, it was noticed that students were not aware that variables could cause an effect in a different part of the world. For example, the deforestation of the Amazon forest is partially due to the cultivation of soya, which is used to produce fodder for intensive farming in Europe. The spatial dimension of these effects is not visualized in current causal diagrams.

Second, the variables used in these diagrams can be interpreted on a different scale. Some of the variables, such as 'prosperity' or 'emission of greenhouse gasses in the atmosphere', should be seen on a global scale, whereas other variables' impact, like 'deforestation' or 'the production of smartphones', is more on a regional scale. In reality, global spatial patterns can be observed with many variables. By emphasizing on the connections between different variables, students' awareness that these variables can be of a different scope seems to be obscured.

This issue is also related to the question whether to use variables or parameters (a specific state of a variable) as nodes in causal diagrams. The current use of variables creates a third problem concerning the spatial scale and time scale. Variables do not evolve at a universal rate, which means that relations between certain variables can diverge geographically. For example, the variables 'urbanization' and 'prosperity' are related to the variable 'variation in diet'. The main idea behind this connection is that people who migrate to a city and who become wealthier will have an increase of sugar, fat and meat in their diet. However, while this may still be the case in many parts of Asia and Africa, it is disputable whether this is still the case in regions with greater prosperity like Europe or Northern America. Thus, it is important to take into account the stage a variable is in.

Fourth, cause-effect relations—represented by arrows in a causal diagram—do not always manifest themselves instantly. Sometimes, effects are immediately observable, but in other cases, effects (or clearly observing them) can be subjected to a time lag. For example, the effects of global warming due to the increase of greenhouse gasses in the atmosphere will only be visible a while after these gasses has been emitted into the atmosphere.

Eventually, it will be necessary to implement a strategy that incorporates the connections between variables but also spatial scales and time scales. Before establishing a different strategy to obtain this, one should consider the appropriate level of abstraction in a geography course in the final two years of high school. Working with case studies for example would create the opportunity to implement detailed information on the location and time lag of the different variables. On the other hand, geography as a course does aim to search for greater patterns and structures in order to achieve insights on a global scale, which is often a more abstract story.

## CONCLUSION

By designing and trying out the course materials, the authors hope to contribute an example about how to use causal diagrams to foster systems thinking in geography courses in high schools. As development occurred within the confines of a theoretical and practical framework, some compromises had to be made. The collaboration with both experts and teachers was crucial to find feasible solutions. The teachers' involvement in the design process also helped them prepare to teach the actual lessons. The teachers' first reflections do reveal they noticed enhanced reasoning when students were constructing causal diagrams. After the implementation of the lesson series, a few important challenges with regard to future adjustments emerged. To convince geography teachers to change their approach in class, it was crucial to align the course material more with the students' level of understanding, to put a larger emphasis on spatial embeddedness, and to find proper methods of assessment.

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