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System Geographical Webbing as an Object of Knowing to Analyze Sustainability Issues in Geography

Systemgeographisches Concept Webbing zur Analyse von Nachhaltigkeitsfragen in Fach Geographie

La red geográfica del sistema como objeto de saber para analizar cuestiones de sostenibilidad en Geografía

Lotta Dessen Jankell ✉, Patrik Johansson

Zusammenfassung Dieser Artikel untersucht systemgeographisches Concept Webbing, d.h. die Verwendung eines Verbindungsnetzes, zur Analyse von Nachhaltigkeitsfragen, als Unterrichtsinhalt im Geographieunterricht der Sekundarstufe II. Hierfür wurde eine Modellaufgabe basierend auf Systemprinzipien und geographischen Konzepten entwickelt. Empirische Daten bestehend aus Unterrichtsinterventionen wurden erhoben und zielen auf die Erstellung von systemgeographischen Zusammenhängen am Beispiel von Nachhaltigkeitsthemen ab. Dieser Artikel beschreibt Aspekte des geographischen Wissens, welche für die Verwendung von Concept Webs und seiner eingebetteten Werkzeuge, sowie zur Erforschung von Nachhaltigkeitsthemen erforderlich sind. Abschließend schlägt der Artikel Möglichkeiten für Lehrerinnen und Lehrer vor, die Entwicklung des geographischen Systemdenkens zu unterstützen.

Schlüsselwörter Geographieunterricht, systemisches Denken, Concept Webbing, Nachhaltigkeitsaspekte

Abstract This article explores system geographical webbing, i.e., to use a specific connection web to analyze sustainability issues, as an object of knowing in upper secondary Geography teaching. A model task was developed based on systems principles and geographical concepts. Empirical data consists of teaching interventions aimed at encouraging students to perform webbing actions and to construct geographical relationships of sustainability issues. The article describes aspects of the geographical knowing needed for using a connection web and its embedded tools to explore sustainability issues. Finally, the article suggests avenues for teachers to support system geographical knowing development.

Keywords Geography teaching, systems thinking, system geographical webbing, sustainability issues

Resumen Este artículo explora el sistema de redes geográficas, es decir, utilizar una red de conexión específica para analizar cuestiones de sostenibilidad, como un objeto de conocimiento en la enseñanza de la Geografía en el bachillerato. Se desarrolló una tarea modelo basada en principios de sistemas y conceptos geográficos. Los datos empíricos consisten en intervenciones didácticas destinadas a incentivar a los estudiantes a realizar acciones de tejido y a construir relaciones geográficas de temas de sostenibilidad. El artículo describe aspectos del conocimiento geográfico necesario para usar una red de conexión y sus herramientas integradas para explorar temas de sostenibilidad. Finalmente, el artículo sugiere vías para que los maestros apoyen el desarrollo del conocimiento geográfico del sistema.

Palabras clave enseñanza de la Geografía, pensamiento sistémico, sistema de redes geográficas, cuestiones de sostenibilidad

1. Introduction

This article presents findings from an educational design study where students learned to construct and use a system geographical connection web to explore, analyze, and interpret sustainability issues. These matters were taught in upper secondary school Geography and addressed challenges currently confronting humanity, such as climate change and the scarcity of resources caused by human consumption and production. Sustainability questions like these are characterized by the complex interconnectedness of their causes and consequences, and the rapid pace of change (Jacobson 2017; Cox et al. 2018). Also, they cannot be explained by simple causalities, but need to be addressed in terms of interwoven causal relationships (Arnold & Wade 2015; Lezak & Thibodeaux 2016).

School Geography aims to teach students about "human activities and their interrelationships and interactions with environments from global to local scales" (IGU-CGE 2016, p. 4). This integrated aspect of geographical knowledge frames the geographical idea of keeping things whole (GA 2012), while contributing to students' geographical relational thinking (Lambert 2017). Understanding the *Human-Earth-relation* as an intertwined system (IGU-CGE 2016) and being able to provide integrated and holistic explanations is an important contribution to Geography education (Maude 2017), especially regarding sustainability issues (Yli-Panula et al. 2020).

However, it is challenging for students to understand and deal with the level of complexity and multicausality that characterizes broad and abstract matters like climate change (Favier & van der Schee 2014; Jordan et al. 2014; Cox et al. 2017). Particularly, it is difficult for them to identify underlying causal relationships (Grotzer & Bell Basca 2003; Karkdijk et al. 2019), to understand relations between local and global levels, and to connect a holistic perspective with specific contexts (Resnick & Wilensky 1999; Penner 2000). In an overview of Geography teaching about sustainability issues, researchers emphasized teaching that enables students to identify and integrate various biophysical and social components in a given environmental context (Yli-Panula et al. 2020). One teaching approach which has been promoted is introducing students to and getting them to practice systems thinking (Hmelo-Silver et al. 2007; Roychoudhury et al. 2017; Yli-Panula et al. 2020). The ability to address complex issues in terms of systems has also been highlighted as a key competence in the Agenda 2030 (UNESCO 2017). This competence can be understood to involve both holistic and relational dimensions. The holistic dimension points to the understanding of the function of a system as a whole, while the relational aspect involves the construction and functions of interwoven (multi-causal) relationships (Karkdijk 2022).

However, there are challenges when epistemic ideas from academic disciplines, such as systems for analysis and modeling, are introduced in teaching. In many countries, including Sweden, where this study was conducted, the systems approach has been offered as a possible perspective in curricula, but systems have not been systematically integrated in Geography teaching practices. Research on geographical relational thinking (Karkdijk et al. 2019) and systems thinking in Geography teaching (Cox et al. 2018), have observed students encountering additional difficulties when introduced to systems. Hence, the introduction of these ideas in teaching is a didactical challenge which encourages interventions that help us better understand what students need to know to be able to use systems to analyze and interpret geographical issues. Karkdijk (2022) has suggested that students need to learn *webbing*, i.e., constructing relationships between pieces of information to get a holistic understanding of a specific geographical problem before trying to solve it. What students need to know to be able to perform this webbing of human activities and processes of nature on multiple spatial and temporal scales, is, however, yet to be discovered.

This study originates in a teaching intervention where systems were introduced as an organizing concept in Geography teaching about two sustainability issues (cf. Dessen

Jankell et al. 2021). Systems ideas were embedded in a model task, referred to as the system geographical connection web in this article, or the connection web for short. One main research question was formulated: what do students need to know to be able to construct and use a system geographical connection web to analyze and interpret a sustainability issue? Based on the investigation, the ambition is to discuss the meaning of system geographical webbing as an aspect of this knowing. In addition, we want to identify and describe indicators of this subject-specific knowing that can be used to assess what might enable and impede this learning.

2. Previous Research

In this section, we present research that describes the challenges students typically face when learning to use systems to address issues related to sustainability. A system is a set of entities connected in a way that gives the system an overall identity and behavior (Arnold & Wade 2015). A systems analysis considers the holistic structure and behavior of a system through its entities and their interconnectedness (Verhoeff et al. 2018). System models are used in several disciplines (e.g., Environmental Geography, Biology and Geosciences), to analyze complex and integrated issues (Castree et al. 2016).

In some countries, the systems approach has been implemented in natural sciences teaching practices (cf. Yoon & Hmelo-Silver 2017) in relation to subject content, such as evolutionary processes (Centola et al. 2000), the aquarium system (Hmelo-Silver et al. 2007), the hydrologic system (Ben-Zvi-Assaraf & Orion 2010), the dynamic and cyclical nature of the Earth's crust (Stieff & Wilensky 2003), and social systems (Booth-Sweeney & Sterman 2000). Most research has described challenges and difficulties related to teaching about systems. Especially in the field of conceptual change, which has contributed with knowledge about outcomes of teaching strategies, individual students' development of systemic skills, competencies and learning strategies in quasi-experimental interventions (e.g., Ben-Zvi-Assaraf & Orion 2005; Hmelo-Silver et al. 2017; Karkdijk et al. 2019).

The main focus has been on what seems to be particularly difficult for students to understand. Four such challenges were of particular interest for the teaching design in this study: (1) students' difficulties grasping underlying causality, (2) the fact that indirect effects are overlooked, (3) students' tendency to reason locally and miss the broader holistic picture, and (4) the challenges posed by considering space and time.

Grotzer and Bell Basca (2003) have identified the difficulties grasping underlying causality that structures all concepts integrated in a system (cf. Favier & van den Schee 2014; Karkdijk et al. 2019). If students do not identify the variety of causal patterns, they are likely to impose a linear pattern of simple cause-and-effect relationships, which may be insufficient (Grotzer & Bell Basca 2003). By introducing activities focusing on the nature of different types of causality (e.g., domino, cyclic and mutual causality), Grotzer and Bell Basca (2003) improved 8–9-year-old students' thinking about causality by influencing the way they structured information, which improved their understanding of ecosystems.

Several researchers studying lower and upper secondary school students have identified difficulties in discerning indirect interactions and their effects on a system level (e.g., Barman et al. 1995; Palmer 1996; Mambrey et al. 2020). Grotzer (1993) showed that students tend to focus on immediate effects while overlooking indirect effects. Jacobson and Wilensky (2014) found that it is easier for students to understand direct relations since it is possible to experience the effects. In comparison, indirect relations, which occur in several steps, remain abstract to our observations. Mambrey et al. (2020) found that being able to identify indirect relations has a greater effect on the understanding of complex systems (e.g., predator–prey systems) than has the identification of many components.

Researchers in various fields have described tendencies to reason locally while disregarding the larger picture (e.g., Resnick & Wilensky 1999; Penner 2000). For instance, Leach et al. (1996) found that students tend to reason about individuals and miss population effects in ecosystems. Strommen (1995) noted that students miss broader conceptual relationships between organisms in a forest habitat, since they focus on animals and do not include plants, insects, or decomposers. These tendencies may become an even greater problem in Geography since the range of processes are wider, ranging from local to global or even planetary scales, often including human actors. Jordan et al. (2014) noted that focusing on a broader, holistic level might impede students' understanding of causal relations on a contextual level in Biology teaching. This reversed problem can become problematic in Geography as well, as there is a significant risk of keeping things too general in relation to global issues like climate change.

Students have difficulty tracing the level of connection between causes and effects in space and time (Grotzer & Bell Basca 2003). The difficulty is that extended domino-like effects are detached in space and time from their causes. Natural systems often contain balancing functions that dampen effects, which make them less noticeable in the environment. Students need to become aware of this fact and consider it in system analyses.

These difficulties affect system understanding and have mainly been studied in school subjects other than Geography. Research about systems in Geography teaching is scarce and has chiefly focused on physical-geographical content, such as the hydrologic system (Ben-Zvi-Assaraf & Orion 2010) or the rock cycle (Stieff & Wilensky 2003).

In Germany and Flanders where complex systems and system thinking are included in Geography education (Cox et al. 2018), research about systems in relation to Geography teaching is more common. A German model (DGfG 2012) for a systems approach has been developed to visualize different relations involved in geographical analysis. The model distinguishes between vertical and horizontal relations that need to be identified to explain regional change (van der Schee 2000). Vertical relations are interactions between human and natural systems within regions. While horizontal relations are interactions between (sub-)regions that describe how changes in one region cause changes in other regions. In addition, Mehren et al. (2018) focused on producing a system competence model with three dimensions that was tested empirically and involved the understanding of system organization, the behavior of systems, and how to use system models to make prognoses.

Cox et al. (2018) used causal diagrams to measure systems thinking skills and to develop students' system abilities in Flanders and concluded that it was difficult for students to use system ideas. Cox et al. (2020) also found that students who enriched causal diagrams with scale tended to develop a functioning geographical framework and improved system skills. This suggests that geographical concepts need to be explicit in Geography teaching with system models to bridge holistic and specific perspectives. Karkdijk (2022) who explored how students' geographical relational thinking developed through *mysteries* (Leat & Nichols 2003) showed that although students constructed and verbalized ideas about relations, most were not able to establish complex systems of relations. However, all students who used a webbing strategy managed to develop more complex understandings. Hence, Karkdijk (2022) requests further research to find out what students need to know to master webbing strategies.

In Sweden, the systems approach has not been systematically included in teaching practices in Geography. Rather, systems have been added as an abstract perspective, only required as "a way to understand the world as intertwined"—specifically in relation to human–nature relations and sustainable development—in the upper secondary Geography curricula (SNAE 2011, GEOGEO01). Consequently, further research is needed to learn more about what students need to know to grasp underlying causality, and to identify the holistic and the specific in various geographical relations extended in space and time, webbed together in a complex system.

3. Theoretical Framework

This study has its origins in a practice theoretical approach, rooted in the assumption that human knowledge and development results from the practices in which we partake (Vygotskij 2001). Hence, knowledge is socially, culturally, and historically constituted through people's tool-mediated actions (Stetsenko & Arievitch 2008). In this epistemological tradition, knowledge is not divided into theory and practice, but seen holistically as different aspects of the same knowing (what people do, how they do it, what tools they use and how they communicate about their doings). Knorr Cetina (1999, 2001, 2005, 2007) distinguishes between epistemic practices and habitual practices as part of knowledge cultures. Epistemic practices, such as Geography as an academic discipline, are characterized by knowledge production in which specific epistemic tools (concepts, models, physical objects, etc.) are developed to solve specific problems. Habitual practices, instead, are characterized and maintained by habitual actions based on routine and traditions embedded in tools. Importantly, tools and actions are not separated in this tradition—there are no actions without tools, and no tools without specific actions.

Using this categorization by Knorr Cetina, teaching in schools could be seen as habitual practices where knowledge is reproduced, while new knowledge in terms of specific epistemic actions and tools is produced elsewhere. However, researchers (e.g., Carlgren 2015) have suggested that teaching could be seen as an epistemic practice focused on the development of knowledge that is unfamiliar, and hence *new*, to the learners. Following this view, teaching can be regarded as an epistemic practice, where knowledge is the teacher's raw material which is to be transformed into the content of teaching, as well as the result of this work, i.e., students' knowing (Carlgren 2015; Eriksson & Lindberg 2016). Knowing, in this sense, can be seen as a capability where the knower (or learner) creates an increasingly more differentiated relationship to the area of knowledge, for example, by being able to make interpretations, formulate questions, use appropriate tools, etc. (Carlgren 2015).

Reflection is an important part of transforming habitual actions into epistemic actions, and differentiating the relationship between the knower and the object of knowing. It is the reflection on one's own actions that sparks the awareness that new perspectives, or ways of using a tool, are needed to solve a problem (Zuckerman 2004). For teaching practices to be considered epistemic practices, teaching must enable these reflections among learners to develop a differentiated relationship between subject-specific objects of knowledge and the students. This is challenging since epistemic objects are often abstract, and students need teachers' guidance to (re-)produce and develop a specific knowing. The goal for educators is to design teaching where epistemic objects can be transformed into content of teaching that can trigger the evolution of students' epistemic actions. This article aims to explore Geography teaching as an epistemic practice and describe the meaning of a specific geographical knowing, namely system geographical webbing.

3.1 System Geographical Webbing as an Object of Knowing

An object of knowing becomes epistemic when learners reflect and change their relationship to the object. As a result, actions in relation to the object change as well (Knorr Cetina 2001). Changes in actions draw the line between habitual and epistemic practices (Knorr Cetina 2001; cf. Eriksson & Lindberg 2016). The object of knowing in this study is referred to as system geographical webbing, which can be seen as a way of dealing with complex issues in Geography based on the idea of systems. This object of knowing involves a combination of what can be seen as *system actions* and *geographical actions*. System actions have been described as identifying components of an issue, connecting these into causal relations, organizing and synthesizing relations into an integrated holistic system, and analyzing and interpreting the whole structure and behaviors of the system through its entities and their interconnectedness (cf. Mehren et al. 2018; Verhoeff et al. 2018).

Geographical actions refer to the way geographers anchor phenomena in certain places and hence, issues are contextualized and mapped (cf. Favier & van der Schee 2014). This geographical contextualization is an important contribution from geographical practices to system modeling and system analysis, since spatial dimensions, such as place-specific circumstances and spatial scale determine consequences and outcomes. Since the object of knowing involves these interconnected actions, it is seen as synthetic. The webbing metaphor explains the character of the synthetic actions and is borrowed from previous research on strategies that students use when dealing with complex geographical issues by connecting pieces of information (Leat & Nichols 2003; Karkdijk 2022). Karkdijk (2022) observed that students who used a *webbing strategy* were more successful in solving complex problems. The webbing strategy involved the construction of a multi-causal web of relations before addressing the problem. Instead of trying to construct linear and logic cause and effect chains, one by one, the students focused on *webbing the pieces together* to understand the holistic picture of the situation through the pieces of information. The students' approach was in line with what professional system modelers would do when addressing geographical problems. Therefore, the synthesis of systemic actions, geographical actions, and webbing actions are considered to be epistemic *system geographical webbing actions*.

3.2 Organizing Concepts

The goal of the teaching intervention was to establish a teaching practice where students' system geographical webbing could evolve. Several systems and geographical conceptual ideas produced in academia using system models were therefore integrated into the teaching design and embedded in a task of constructing a connection web (see next section). These conceptual ideas were operationalized as organizing concepts (cf. Dessen Jankell et al. 2021), through which aspects of system geographical knowing could be mediated and transformed into epistemic system-geographical actions. Organizing concepts are subject-specific and include propositional knowledge as well as actions and uses of tools which link everyday experiences with theoretical levels of the subject (Taylor 2008)—for example, ways to ask questions, select data, analyze, and interpret information. Hence, organizing concepts are considered to have the potential to bridge the gap between ideas, experiences, and processes in Geography teaching (Brooks 2018). By using a design in which these concepts were used, the actions and the propositional knowledge embedded in them could be mediated. The organizing concepts are presented below, as well as the potential knowing that could be mediated:

Systems: Systems as a concept can be defined as specific entities connected in a way that gives the system an overall identity and behavior (Arnold & Wade 2015). Organizing the world (or an issue) in terms of systems involves actions of constructing an integrated web-like structure consisting of causal relations. It also involves analyzing the integrated structure of the system, its function and its behavior through its entities and relationships (Mehren et al. 2018). This involves being able to identify behavioral aspects of relationships, which means how components affect other components. For example, indirect effects, non-linear, dynamic, and multi-causal relationships, drivers of the system, positive correlations (i.e., components which affect each other in the same direction—increase/increase or decrease/decrease) and negative correlations (i.e., components which affect each other in the opposite direction—increase/decrease) and interpret what would happen if components changed. These behavioral aspects were all embedded in the task.

Causal connections: These kinds of relations form the structural base of the construction of a system (Mehren et al. 2018). When organizing an issue in terms of causal connections it is important that components are specific (e.g., albedo effect, fossil fuel release, or outsourcing) and that the connections are based on direct causality. Otherwise, it is impossible to make a system analysis (Mambrey et al. 2020).

Place: The concept of place can be considered the *raw material* of Geography (Rawling 2018) and as such it inherits substantial and descriptive knowledge in terms of names, absolute and relative location, place contexts, and characterizations of places (Lambert 2011). Actions involved in organizing issues using place are, for example, asking questions relating to where something occurs, what the function of a place is, or what the consequences are if something happens at a certain place compared to another (Cresswell 2015). Using place in system analysis is about being able to connect components to specific places (Favier & van der Schee 2014) as a way to visualize connections between human activities and processes of nature within specific regions (vertical relations) and between regions (horizontal relations) (van der Schee 2000).

Scale: The concept of scale can be defined as a predetermined lens through which the world is observed (Lambert & Morgan 2010) and a tool in Geography "to organize geographical content" (Cox et al. 2020, p. 114). By using scale, it is possible to arrange and interlink facts and events (e.g., climate change) at local, regional, and global levels (LAMBERT 2011). This enables the interconnection of people's actions and environments at one scale with another, and to interpret consequences at various levels.

4. Method and Sample

The intervention followed a general pattern for educational development research (cf., MCKENNY & REEVES 2014) where the teaching design and the task were constructed in collaboration with participating teachers. The main researcher (a qualified Geography teacher) selected the organizing tools (i.e., systems, causal connections, place, and scale) as a way to counter challenges and obstacles faced by the students, and that had been identified through previous research into Geography teaching (cf. COX ET AL. 2018; KARKDIJK 2022) and related fields like Biology and Geoscience. The participating teachers contributed with their experience and challenges that they had identified from teaching similar issues. The researcher and the teachers formed the research group.

4.1 Participants

The participating teachers were experienced Geography teachers with more than ten years of teaching experience and used to working with sustainability issues in interdisciplinary teaching. The teachers and students came from two socio-economically diverse urban upper secondary schools in Sweden. The teachers were previously known to the researcher as former colleagues or members of a network of teachers participating in a sustainability course. All teachers volunteered to participate in the research after being asked if they were interested in exploring systems as a didactical approach. None of the teachers had previous experience with system models. The observed classes were selected from those taught by the participating teachers. The seven participating students from each school who were recorded were randomly chosen. Gender and grades were disregarded as variables in the selection since comparisons were not part of the research purpose. Permission to conduct this research was granted by the Ethics Committee in Sweden, and the study follows the ethical guidelines of the Swedish Research Council. All participants were informed about the research project before data collection commenced and only those who consented in writing to voluntarily participate were included in the data. All participants were informed that they could withdraw from the research project at any time.

4.2 Teaching Design

In each school, the teaching intervention was staged as part of a series of lessons stretching over five weeks, divided into three segments: (1) lessons on sustainability issues, (2) groups

Schools	Students	Teachers
X Upper secondary school (800 students)	*n*=60 (2 classes) Participated in observed lessons *n*=7 (3 boys, 4 girls) Participated in recorded group work	*n*=4 Worked together with two classes
Y Upper secondary school (1,200 students)	*n*=30 (one class) Participated in observed lessons *n*=7 (2 boys, 5 girls) Participated in recorded group work	*n*=2 Worked together with one class

Fig. 1. Participants in the study (Source: authors)

collaborating in an enquiry about a sustainability issue, and (3) an individual exam. The intervention with the connection web task was introduced during two 80-minute lessons in the second segment. The students were familiar with the sustainability issue, basic concepts and most of the content, and the task was seen as preparation for the final exam. In the first lesson (Fig. 1), students were instructed and started constructing models in groups of three to four students. The preliminary connection webs were collected and analyzed by the research group to inform revisions to the teaching. Hence, the construction of connection models was taught in an iterative process where the teachers became active in the research process (McKenny & Reeves 2014). Based on the analysis of the models, the second lesson started with whole-class feedback to encourage students to adjust and refine their models.

4.3 The Model Task

The intervention involved the construction of a *system geographical connection model* to analyze two sustainability issues. In school X, the enquiry was: *How does consumption and production affect people and the environment in different places on earth? (Global trade case)*. In school Y, the enquiry was: *How does climate change affect the Arctic region and, in turn, affect living conditions in other locations on Earth? (Arctic case)*. The model task involved the organizing concepts presented in section 3.2 to stimulate system geographical webbing actions accordingly (see Appendix 1 for instructions to students):

Systems: The task was to connect subject-specific content selected for each issue in terms of concepts students had worked with (i.e., global warming, biodiversity, consumption, etc.) written on paper notes. The paper notes could be seen as components which could be connected to each other with arrows to form meaningful connections. The behaviors of the connections could be visualized with a plus (+) if it was a *positive correlation* (i.e., same direction) and minus (–) if it was a *negative correlation* (opposite direction). Students practiced using the symbols when the task was introduced, and components were integrated into a weblike system when the task was done.

Causal connections: The enquiry involved a variation of connections that aimed to inspire the construction of causal connections by connecting components with arrows in various ways: *direct causal relations* (A →B), *indirect* (A → B and C), *multi-causal* (A and B → C and D), *mutual* (A ← → B) relations. Students practiced this before the task (Fig. 3).

Place: Each enquiry encouraged the use of maps, texts, and colors to visualize the *location* of components and *place contexts* (e.g., details about local circumstances). Anchoring components in specific locations should enable the analysis of how events in one place affect humans and nature in the same region (vertical relationships) or in other regions (horizontally).

Scale: The task involved analyses on different scales and the students chose symbols for visualizing global, local, and regional scales.

4.4 Data and Analysis

As illustrated in Fig. 2, data were collected during two lessons in part II of the lesson series, which took place at each school. The data consist of video and sound recordings of the students' group work (14 students in total, 7 in each school), their connection web models, and field notes and observations of whole-class activity (Fig. 2). The data were analyzed in several steps, influenced by thematic analysis (Braun & Clarke 2006). First, all data were transcribed and then all passages where the students' epistemic actions were in line with the organizing concepts, were coded (i.e., sys-

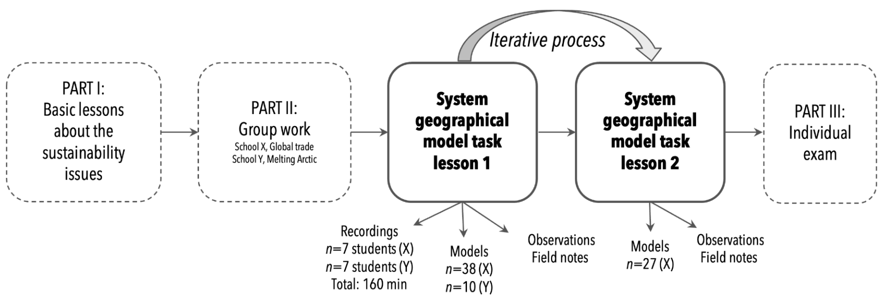

Fig. 2. Schematic diagram of the intervention and data collection (Source: authors)

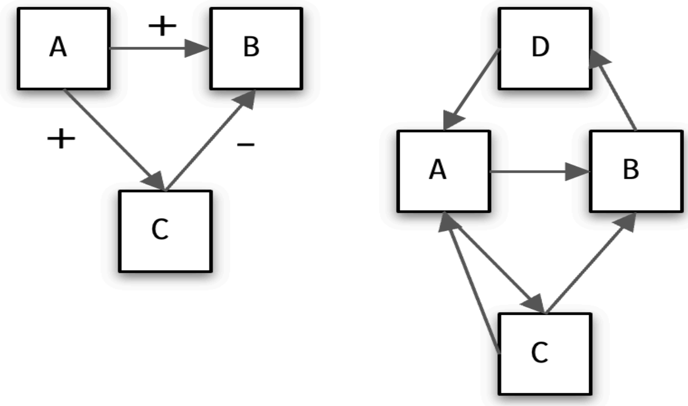

Fig. 3. The different connections and symbols that the students were instructed to use (Source: authors)

tems, causal connections, place, scale). The exact categories were not decided beforehand but were influenced by what the students did, and the potential system geographical webbing actions embedded in the organizing concepts. For example, when students reasoned in the following way: *transport is causing increases in CO_2 globally*, and consequently constructed a connection using an arrow and the plus sign between the notes transport and CO_2, the passage was coded as *causal-oriented*, *correlating behavior,* and *scale-oriented*. Six main categories of actions were identified: system-oriented actions, causal-oriented actions, behavioral-oriented actions, place-specific oriented actions, and scale-oriented actions. There was also one category called sustainability-oriented actions that concerned actions where students interpreted consequences in relation to different sustainability perspectives.

Hence, the data were coded using the organizing concepts as a guide to find segments where epistemic actions might have been established. Passages could be labelled with more than one code. Thirdly, salient segments were selected based on theoretical coding for detailed analysis of the characteristics of the students' actions. Indications of epistemic actions in line with the object of knowing were identified, guided by analytical questions like: Who is doing what with what tools? What structures and connections are made? What questions are asked? and what interpretations are made? Video and sound recordings, combined with the constructed models, were used jointly in the analysis. The actions that were identified consisted of reasoning, questioning, arguing, moving paper notes, constructing connections, using arrows and colors, etc. Habitual actions were analyzed as well. Specifically, moments where students reflected on their actions were noted to identify indications of transformations from habitual to epistemic actions. For example, when the students reflected on the fact that an arrow could be used as a tool to visualize the direction of causality, rather than as a tool to categorize concepts. Impediments were noted as well. Field notes from observations and finished connection webs were also compared with the recorded material to see how the recorded samples represented the whole-class activity. The result are four themes that describe aspects and indicators of the intended epistemic knowing of system geographical webbing, as well as a tentative progression for developing the knowing (Fig. 4).

5. Results

Constructing a system geographical connection web to explore a sustainability issue is a complex task for students of any age. In the interventions, however, most students were engaged and inspired by the task, although they found it challenging. The lessons turned into an inspiring, collaborative, and explorative enquiry for many as they strove to construct the integrated system, analyze consequences, and interpret the issues. However, there were differences in how students approached the task, used the tools, and progressed in development of the intended knowing. The analysis identified four qualitatively different aspects

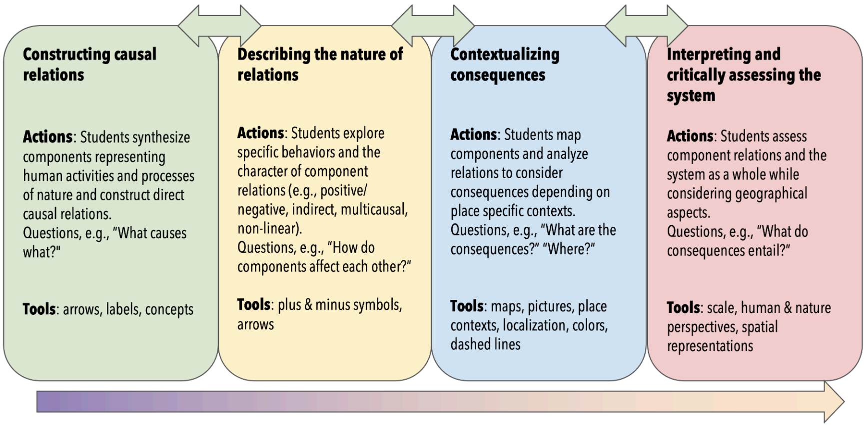

Fig. 4. Four aspects of the knowing of system geographical webbing (Source: authors)

of system geographical webbing that describe what this knowing entails in terms of characters of actions and uses of tools (Fig. 4). The analysis revealed a tentative progression of the intended knowing, although the process cannot be considered linear.

Four qualitatively different aspects of the intended knowing of system geographical webbing are described as characteristics of actions and uses of tools involved in constructing a system geographical web to interpret a sustainability issue. The arrow below Fig. 4 indicates a tentative progression, while the double-sided arrows at the top point to the iterative aspect of the process.

5.1 Constructing Causal Relations

The first aspect of the intended knowing refers to the construction of causal connections and associated actions and tools. The ability to construct causal relations is a fundamental base for a functioning system (Mehren et al. 2018). The analysis of data shows that the task motivated students to jointly reason about the components and how to relate them to each other. However, it did not mean that the students automatically constructed causal connections. Two indicators of actions and uses of tools reflecting the meaning of this causal aspect of the knowing were identified. These include (a) transforming subject-specific content into components with causal functions, and (b) constructing direct causal connections using arrows to visualize the causal direction (Fig. 5). An indication that the students reflected on the subject-specific content with causal functions was that their reasoning was driven by *what causes what* questions. Another indicator was that the students explicitly searched for direct connections and used arrows as tools to visualize the direction of causality (Fig. 5). When these ways of organizing and connecting components were established, students continued to explore causal functions and meanings. Relevant causal connections were constructed between human activities and processes of nature, as well as between nature–nature and human–human relations (Appendix 1). Students who were not familiar with some concepts asked fellow students for help. Gradually, the meanings of the concepts became increasingly more differentiated.

However, several factors impeded these actions. One example is when students constructed indirect rather than direct relationships which re-

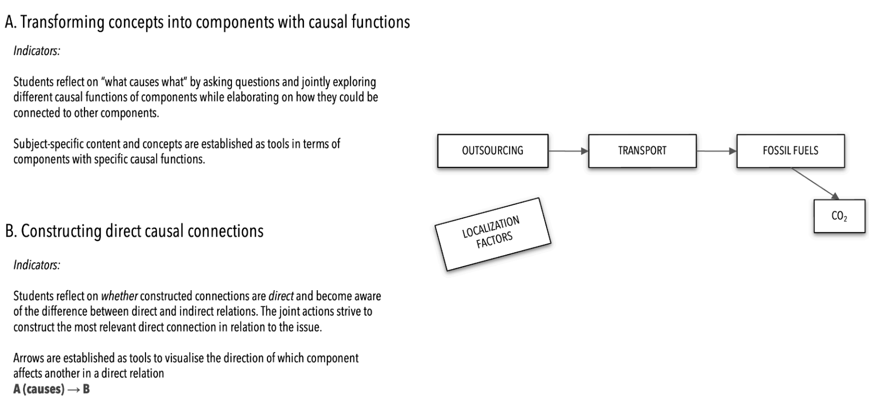

Fig. 5. Indicators of causal connections constructed by the students (Source: authors)

sulted in crucial links disappearing from the connection web (Fig. 6, Example A). Relationships then became too simplified. It may be that the students were not familiar with the specific concepts, or that they did not understand the function of the arrow. Example B (Fig. 6) shows a model in which students had placed concepts of similar character together. The students reflected on the fact that they did not know the meaning of *fertilizers*, *eutrophication*, or *pesticides*, and therefore *put them together where they belonged*. Instead of exploring the concepts further, the students categorized the concepts and went on to the next component. Students' lack of conceptual knowledge clearly impeded the construction of the causal connections (cf. Mambrey et al. 2020).

Another indicator was the students' experiences of the arrow. In school practices, there are many ways to use arrows as tools, including to categorize, or to point to something. These habitual actions hindered several students' reflections on the arrow's role in constructing valid causal chains. The design of the task, however, gave the students opportunity to reason around the constructed relations. This then gave teachers the opportunity to observe whether the arrow was used as a tool to categorize instead of to indicate causal connections. With support, habitual actions could transform into epistemic actions, where the arrow mediated the direction of causality. Hence, the teacher's tutoring was crucial to triggering students' reflections about what kind of relationships they constructed and that triggered further investigations.

5.2 Describing Relational Behaviors

The second aspect of the intended knowing refers to actions and uses of tools involved in specifying relational behavior, i.e., describing *how* components affect each other, which, in turn, determines the nature and dynamics of the entire system. The task aimed at motivating students to reflect on positive and negative correlations, as well as indirect, multi-causal and dynamic behaviors and to use arrows and plus and minus symbols to visualize these behaviors. Four indicators of actions and uses of tools were identified as reflecting this aspect: (1) specifying direct relationships and identifying indirect effects, (2) identifying components that affect each other in the same or opposite directions with the use of plus and minus symbols, (3) describing and visualizing multi-causal relations, and (4) non-linear and dynamic relationships (Fig.7).

The first indicator points to the fact that students needed to reflect on differences between direct and indirect consequences to understand system geographical webbing. Example A (Fig. 7) illustrates a model where the students explored the relationship between *carbon dioxide* and *flooding*. In their search for *direct* factors that cause flooding (e.g., *glacier ice* melting), the students needed to reflect on different melting processes. As a result, otherwise hidden components (e.g., *permafrost-methane-CO_2-air temperature*) and indirect effects were added. As the students reflected on and jointly explored direct effects, the causal chains became more precise and connection webs more complex. The students' conceptual understandings developed as more specific components were added to the webs.

The second indicator involved the use of plus (+) to show *positive correlations* and minus (–) to show *negative correlations*. It was obvious that the students were not used to reflecting on connections in this way, nor using these symbols in the intended way in Geography. The in-

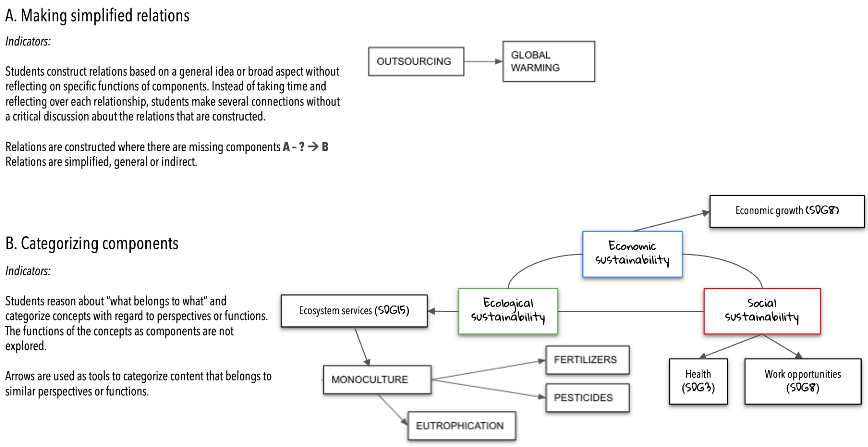

Fig. 6. Indicators of actions that were not in line with the object of knowing (Source: authors)

troduction of these tools stimulated discussions on how the tools were used and how components affected each other. An indicator that the symbols manifested as tools to visualize positive and negative correlations, was the use of *opposite* or *same* direction when explaining how components affected each other. Example B (Fig. 7) shows a model where the students used plus and minus symbols to visualize these correlations. The students stopped and discussed the relationships before adding the symbols, and hence the character of actions became explorative and resulted in more complex modeling.

Adding to complexity, the task prompted students to reflect on multi-causal, non-linear, and dynamic aspects of the relationships too, as more details were added. Multi-causal aspects often started out as linear chains (Example C, Fig. 7) and developed into more complex causal chains when students collaborated to describe how the multiple causes and consequences could be related to each other. A nested structure (Example D, grey arrows, Fig. 7) started to form when more components were added. Students became aware of dynamic and non-linear aspects when they reflected on how components *affect each other mutually*, or *feedback effects*, or that a relationship was *circular*. Challenges emerged as the focus on multi-causal relationships inspired students to construct broader and more general relations, instead of specific causal connections. The result was that crucial components were missing.

Occasionally, the construction of non-linear and dynamic relationships *stopped* at single and linear connections (e.g., between *global warming–drought/flooding–monoculture–biodiversity*), which is illustrated in Fig. 8. The teachers had to encourage students to proceed to construct specific relationships and to reconnect linear relationships to an integrated web. This encouragement invited students to reflect on how specific components could be related, e.g., how *drought* and *flooding* could affect humans. This pushed the students to synthesize components further. Concepts like *resilience* or *ecosystem services* became important *bridges* in the construction of an integrated system.

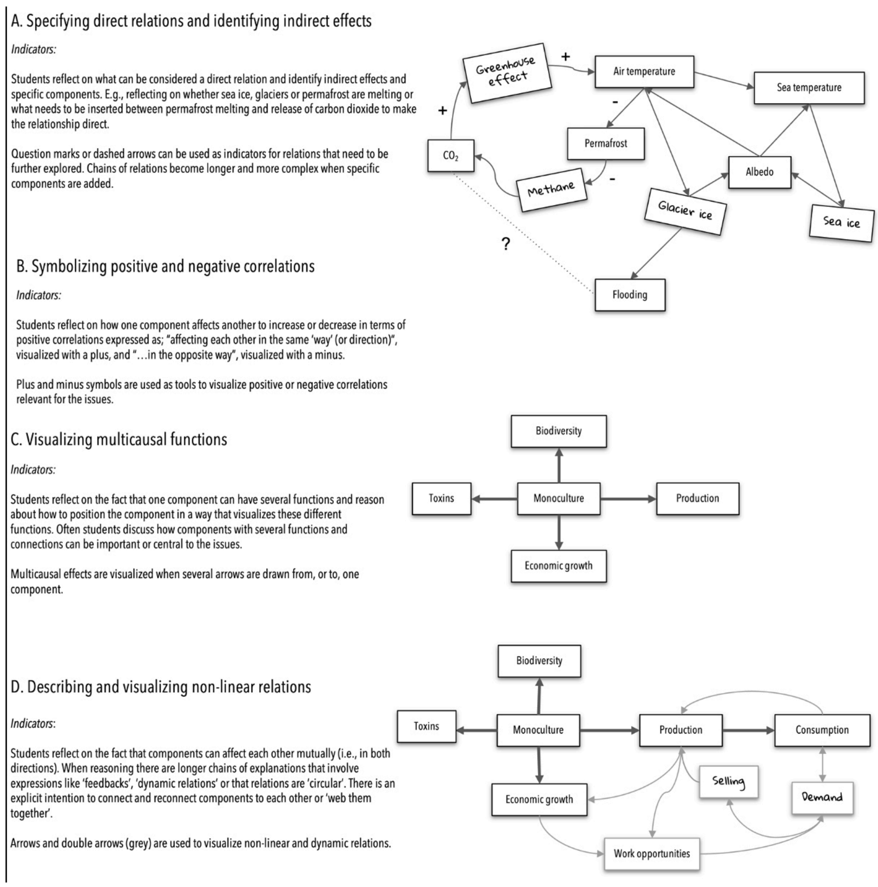

Fig. 7. Indicators of students' exploration of the behavior of relationships (Source: authors)

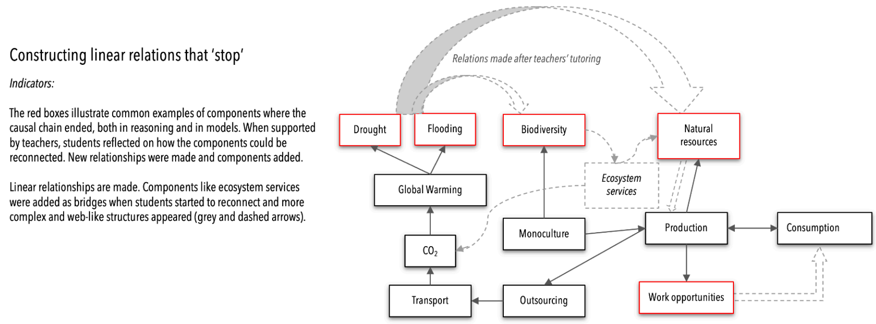

Fig. 8. Indicators of relationships that *stopped* and where students needed the teacher's support to reconnect components (Source: authors)

5.3 Contextualizing Consequences Using Place and Spatial Dimensions

The third aspect of system geographical webbing refers to the geographical contextualization of the constructed relationships, and the importance of anchoring the system in specific places. This addition of spatial dimensions, such as place-specific circumstances to map the issues and determine consequences and outcomes, is a contribution to system modeling and system analysis from geographical practices. Observations of the first iteration show that these aspects often remained implicit. Students typically did not reflect on spatial aspects when explaining and analyzing consequences. In the global trade case, the spatial aspects were absent during the first lesson. This reflects an absence of *localization* (e.g., where production of raw materials occurred), *place contexts* (e.g., circumstances at specific places), *spatial relations* (e.g., between producer countries and consumers), and *scale* (e.g., locally, regionally, or globally). In the Arctic case, vertical relationships became explicit as the specific issue pushed students to explain regional changes (Fig. 9). However, global aspects of climate change were left implicit, as well as local contexts and horizontal relations. The absence of these aspects made it difficult for students to explain how changes in the Arctic affected other places on Earth.

The teachers' prompting was needed for these aspects to become part of the students' reasoning, whereafter there were several indications that the students reflected on place-specific dimensions, which, in turn, had effects on how consequences were elaborated. For instance, students noted how work conditions would differ depending on where outsourcing or *jumping* took place (Fig. 9). Uncertain consequences and conflicts of interest in the Arctic became explicit when students reflected on which nations were involved and what resources existed in specific places (Fig. 9). When mapping the consequences in relation to place contexts, these uncertainties became crucial in understanding complexity in the sustainability issues (Block et al. 2019). Some students visualized uncertainties with dashed arrows (Fig. 9). In summary, the students' perceptions of the issues became more concrete and nuanced when questions about where something occurred were triggered.

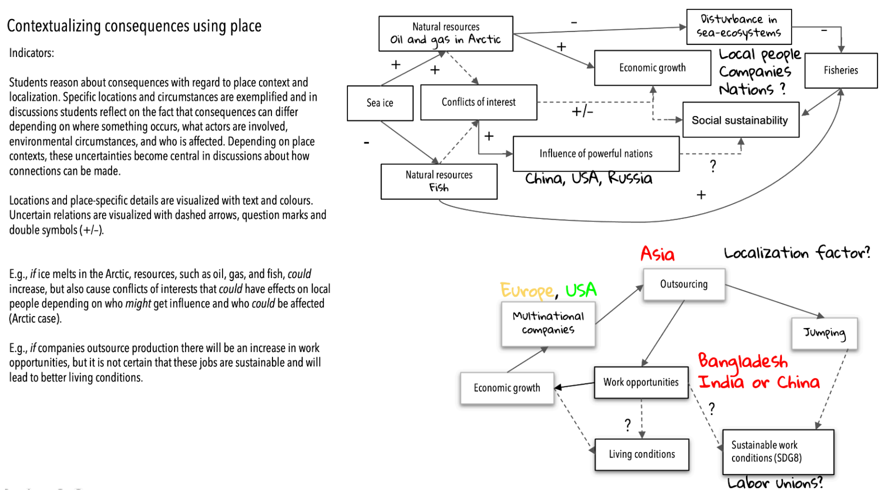

Fig. 9. Indicators of students' contextualization and analysis of consequences based on spatial aspects (Source: authors)

5.4 Interpreting and Critically Assessing the System

The fourth aspect of system geographical webbing refers to the interpretation and critical assessment of the issues based on the entities that were *webbed* into systems. The goal for the students was to interpret *what the consequences meant* by merging the web of relationships to make a holistic conclusion based on the specific and contextualized entities of the sustainability issues. It was challenging for many students to explain the broad, general picture that emerged through qualified assessments of specific processes and vice versa (cf. JORDAN ET AL. 2014). The interpretative actions that were identified differed depending on what constituted the students' modeling work, which included, (a) sustainability perspectives, (b) causality, behavior and sustainability perspectives, (c) place-specific contexts and scale, and (d) the idea of an integrated system based on causal connections.

The first type of interpretative work was guided by the evaluation of consequences as being *sustainable* or *unsustainable*. The students were used to interpreting and evaluating consequences using ecological, economic, and social perspectives since they had worked with the issues for several weeks. These experiences were used in various ways. For some students, the experience of interpreting consequences using sustainability perspectives impeded reflections about specific causal or behavioral aspects as a base for their interpretations. Some students *jumped to conclusions* regarding consequences, instead of analyzing the specific relationships. This meant that habitual actions were established. While modeling, students often used colors to visualize sustainability (green arrows) and unsustainability (red arrows) (Example A, Fig. 10). When sustainability perspectives dominated, relationships were often indirect or unspecific. In many cases, plus and minus symbols seemed to hinder interpretations as these symbols carry habitual meanings of something as being *good* (positive) or *bad* (negative). This led students astray in their interpretations and caused them to jump to assessing consequences as being sustainable or not (i.e., *good* or *bad*), not based on the actual causality or behavior. The symbols lost their mathematical meaning, and the students could not use them to underpin their argumentation.

The second type of interpretation was constituted by the way students merged earlier experiences of sustainability perspectives, with *new* experiences of constructing causal relations and describing behavioral aspects. Habitual *sustainability-oriented* actions transformed into epistemic *system geographical webbing actions*, as students reflected on each constructed connection *before* assessing the sustainability of consequences. These actions added important aspects to the issues and made interpretations more precise. This reflective work could be observed when students combined tools for causality (arrows) with behavioral tools (+/–), with red and green arrows, and SDGs (Example B, Fig. 10 and Fig. 11). A professional system modeler might argue that this combination would be incorrect, but in terms of learning, this combination of tools appeared to support the students in differentiating between describing and analyzing causal relationships and interpreting consequences. Students also used these models to critically discuss solutions. Example B (Fig. 10) illustrates a model used to discuss how *local production* could decrease global warming and be a sustainable solution, while also being unsustainable if work opportunities decreased.

The third type of interpretation was guided by spatial aspects (e.g., place, location, and scale). Students reflected on *where* something occurred and at what scale *before* drawing conclusions about consequences. When encouraged by the teachers to include scale, locations, and place-specific examples, students created symbols and searched for details together. Example C (Fig. 10 and Fig. 11) exemplify typical models where the students used a globe to visualize global scale, a house to visualize local scale, and text to visualize regions or specific factual knowledge. Using place and scale in modeling work inspired students to involve spatial aspects in assessing how consequences could differ depending on where they occurred (cf. COX ET AL. 2020). Example C (Fig. 10) illustrates how palm oil produced in local monocultures in the Brazilian rainforest would affect ecosystem services locally and regionally and have effects on climate globally (Fig. 11). The spatial dimension and causality made students aware that the situation could be different if the monocultures were located elsewhere or if another oil was produced.

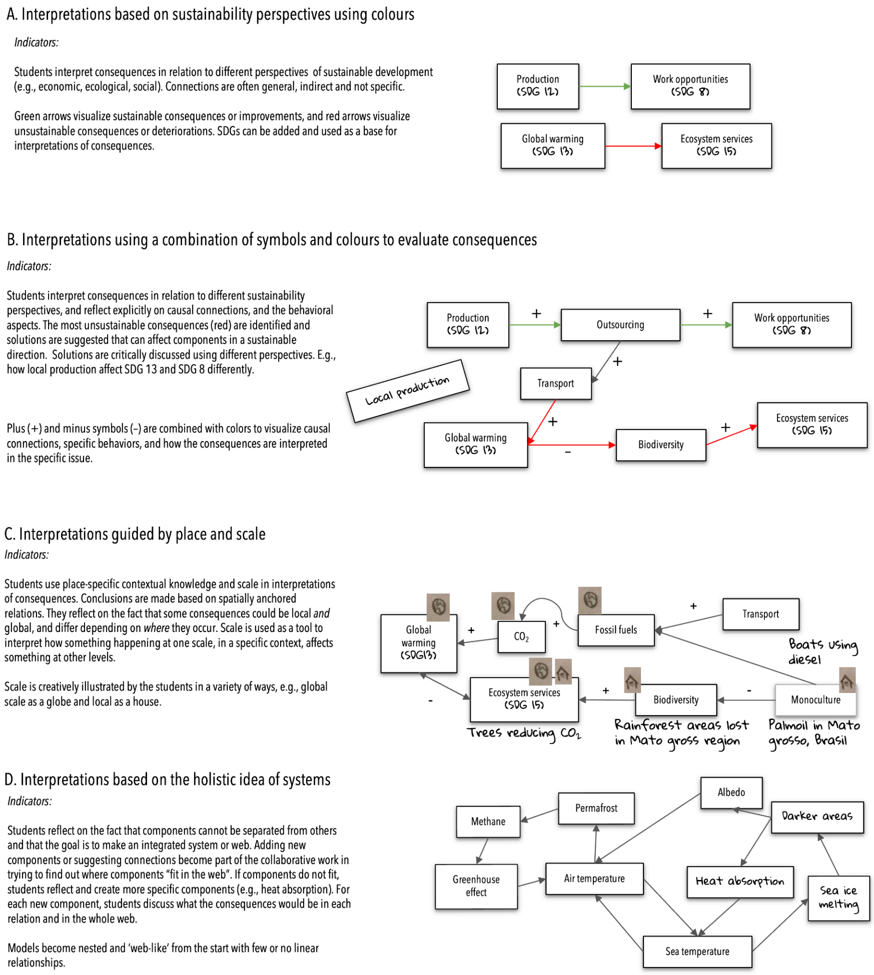

Fig. 10. Indicators of how students interpret, assess and evaluate consequences and the holistic system (Source: authors)

The fourth type of interpretation was guided by the idea of an integrated web of relationships. These actions were challenging for most students, while also being the strongest *webbing aspect* of the knowing. In one group, the students were guided by their idea of creating an integrated system or *web* throughout the task. The students reflected on each component they added in relation to how that would affect the whole system. Example D (Fig. 10) is an illustration of how this group constructed a web to visualize causes and consequences of climate change in the Arctic, while continuously discussing the meaning of each component in relation to other components *and* the whole system. They added more specific components when needed, and the causal functions and behaviors of each relation became

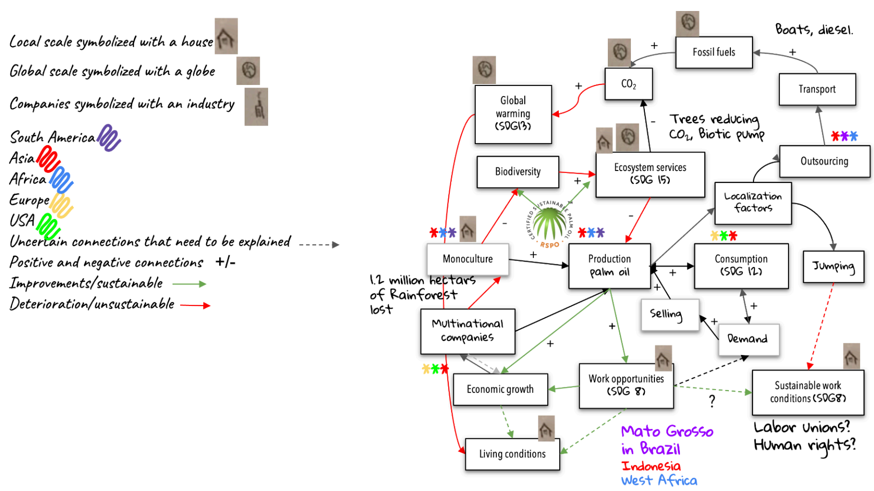

Fig. 11. Empirical example of how students used several aspects of the models to interpret and assess consequences (Source: authors)

part of the conclusion about what would happen if the Arctic melted. These students argued about the assessment of the specific details quite a lot. All these students used the connections as arguments for what could happen in the system. This awareness bridged the challenges of merging holistic views with detailed knowledge (cf. JORDAN ET AL. 2014). However, only one group of students was guided explicitly by the idea of an integrated system throughout the whole task. In other groups, the system idea gradually evolved, but in the end many students used the models as analytical tools to reflect on the issues from a holistic perspective based on the specific connections.

6. Concluding Discussion

Scholars from several educational fields emphasize the use of systems as an approach when teaching to support students' understandings of an integrated and complex world (MEHREN ET AL. 2018; COX ET AL. 2018). In addition, psychologists have found that system thinkers tend to recognize risks posed by climate change, believe in scientific consensus, and support interventions to address climate change (LEZAK & THIBODEAU 2016). However, there are challenges when tools and ideas developed in epistemic practices are introduced in teaching. The aim of this paper was to shed light on what students need to know to be able to construct system geographical connection webs and use these to explore sustainability issues. The analysis identified four aspects of what the knowing of system geographical webbing entails: (1) transforming concepts into components, constructing causal connections and *webbing* them into an integrated system; (2) specifying and describing the behavior of relationships; (3) using spatial dimensions (e.g., location, place contexts, and scale) to map and contextualize consequences and establish geographical relations; and (4) interpreting and assessing the issues based on the whole web-like system through the geographical connections.

Indications that students constructed causal connections were: reflections about the concepts *as* components with causal functions and *what causes what* questions instead of *what belongs to what* questions. The arrows became a tool to visualize direct causal relationships instead of indirect, simplified, or incorrect relationships. These proved to be challenging actions (cf. GROTZER & BELL BASCA 2003; FAVIER & VAN DEN SCHEE 2014; KARKDIJK ET AL. 2019), especially identifying indirect relationships (JACOBSON & WILENSKY 2006; VERHOEFF ET AL. 2018). When the students did not construct direct causal connections, the foundation of the integrated web was not established. We agree with MAMBREY ET AL. (2020) that it is more important to be able to differentiate between direct and indirect relations than to identify many components, since indirect aspects contribute to the students' understandings of the depth and complexity of issues. Therefore, we emphasize the importance of encouraging students to search for direct connections because that resulted in more precise models as hidden components and indirect effects then became explicit. The ability to explain indirect consequences is a qualitative aspect of systems thinking (BEN-ZVI ASSARAF & ORION 2010). When models became precise, students were more likely to avoid coming to *quick conclusions* about sustainability.

In addition, it is important to enable students to establish a correct relationship to +/– symbols as instruments for visualizing the behavior of connections. The results show that using plus and minus symbols to indicate behavior was challenging because some students used them habitually as tools to evaluate something as being *good* or *bad*. Similarly, students' experiences with using sustainability perspectives could trigger them to *jump* to evaluate statements regarding consequences, rather than to explore connections in depth. In these instances, the epistemic foundation for system geographical webbing was impeded.

The establishment of geographical aspects indicated that the students' webbing practice tended to transform from being general into becoming more specific and precise. JORDAN ET AL. (2014) found that it is difficult for students to make qualified assessments between broad and specific processes in explanations. We found that it is possible to improve the students' ability to make more precise assessments when they are encouraged to involve geographical aspects like place and scale (cf. Cox et al. 2020). When the students reflected on where something occurred, they were more likely to realize that consequences differ between places. In addition, without scale, it was difficult for the students to trace domino-like effects that were detached from their causes in space and time (Grotzer & Bell Basca 2003). The addition of scale enabled students to trace effects by visualizing different scales. This triggered the use of scale as a tool to analyze how one local phenomenon affected another, on a different scale.

A final indication that appears to determine the students' system geographical webbing practice is that they explicitly reflected on the purpose of the task as being *to make an integrated system*. The idea of an imagined web-like system guided the students' actions as they continuously explored new components. The teachers frequently needed to encourage them to *reconnect* components to stimulate further integrations. Hence, it is desirable to establish the holistic view of an integrated system from the outset to enable qualitative webbing actions (cf. Karkdijk 2022).

The task involved concepts and tools that the students were familiar with, which triggered habitual actions, such as categorizing concepts and using arrows to group content. Consequently, their reasoning became too general and oversimplified. In line with Karkdijk (2022), we argue that it is preferable to enable students to verbalize and visualize each step of the process, since it is easier for them to reflect on their actions and uses of tools. Then teachers can observe if epistemic actions, as opposed to habitual actions, are established, and determine whether challenges depend on lack of contextual knowledge or the use of tools (cf. Mambrey et al. 2020).

This was an explorative study with a limited number of students, so our observations are only tentative and should be tested further in larger design studies with bigger groups of students. However, in summary, we propose that it can be fruitful to introduce a system geographical webbing model in Geography teaching. For many students, the connection web became a tool to structure the content as the work with the task inspired them to ask relevant questions and to explore the sustainability issues further. Consequently, working with the connection web deepened their knowledge of content, geographical concepts, and systems. In many cases, the model also enabled complex analyses and interpretations of sustainability issues. However, based on our observations, we think it is important to point out that all four aspects of the knowing of system geographical webbing probably need to be established, and therefore teaching needs to be designed in a way that makes this possible. Without one of the suggested aspects, the synthesized knowing runs the risk of being incomplete. Future research could investigate how the four suggested aspects can contribute to the teaching and learning of complex sustainability issues. An important observation, however, is that establishing the desired actions among the students requires time, practice, and the teachers' support. Therefore, we suggest that the connection web model should primarily be used as a tool for teaching and learning, rather than as a tool to test students' knowledge (cf. Mehren et al. 2018; Cox et al. 2018). We think these observations can be valuable for Geography teachers and educators who want to start testing systems as an approach in their teaching about sustainability issues. For example, the connection web could function as an analytical tool for students, and as a platform for the teachers' feedback.

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Appendix

Instructions to the students (original in Swedish).

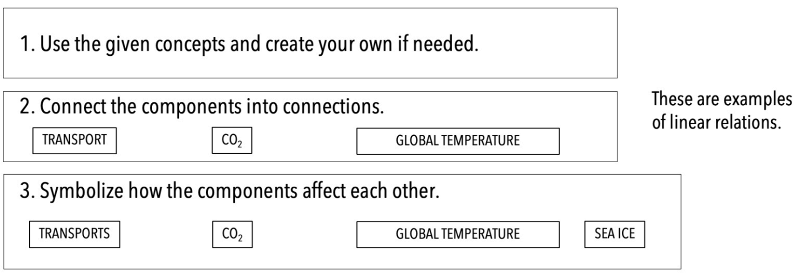
Purpose of task [as presented by the teachers]

The purpose of this task is to find out how different factors that you have learned about over the past few weeks in your group work affect each other and are connected in an entire system. The model you will construct can be used to learn about how something affects something else, but also what happens if something changes. The idea is that you should be able to use the model to answer the bigger question you have worked on during your group work.

How does consumption and production affect people and the environment in different places on Earth? (School X)

How does climate change affect the Arctic region and how does that, in turn, affect living conditions in other places on Earth? (School Y)

Instructions on how to make a system model (web of connections)

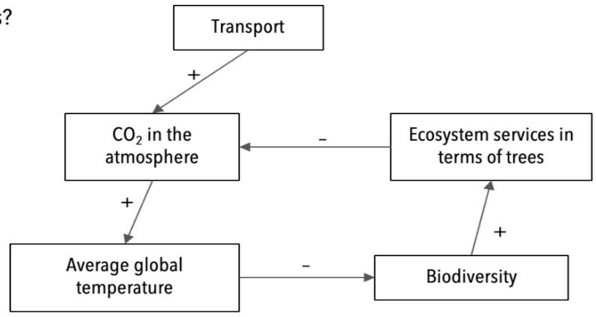


Same direction = positive relation = +
Different direction = negative relation = -
You can also use words to explain the relation if you want.

4. Dynamic relations

When transport with fossil fuels increases it means that the amount of CO_2 in the atmosphere increases and that causes the average global temperature to rise as well. This reduces biodiversity, since species can't adjust to the new environment that the climate causes. Then ecosystem services decrease, for example trees, which reduce their carbon dioxide uptake. This will cause carbon dioxide in the atmosphere to increase even more.

How can we visualize such a dynamic relation?
How do humans affect the system?
How does the system affect humans?



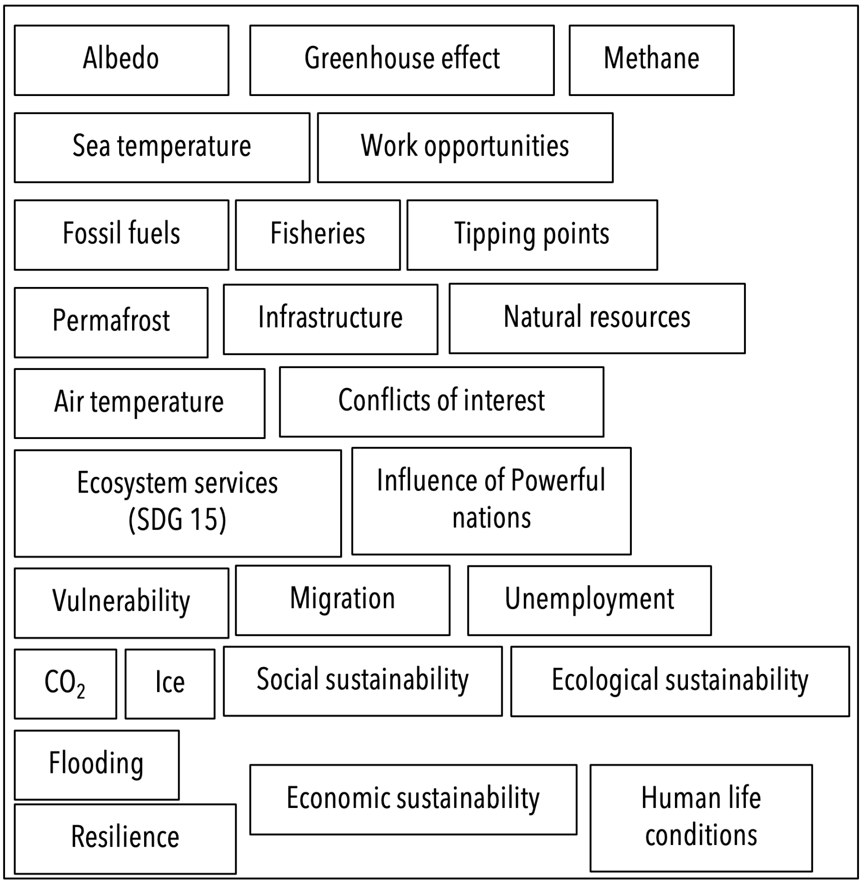
5. Make your model specific

To be able to analyze consequences, you need to be specific. Use the group work you have done as a knowledge background to specify details about the components. It is important to specify ***where*** *something occurs and visualize the geographical location in your model. You can do this by using colors or text. For example the colors used in Gapminder. You can also visualize at what scale something occurs (local, regional, global) and create symbols for this.*

There might be actors you want to show, different perspectives (ecological, economic, social) or different levels, such as individual, group or societal level.
This will make your model more concrete.

- Consumption (SDG 12)
- Sustainable space inside Planetary boundaries
- Resilience
- Natural resources
- Outsourcing
- Economic growth
- Fossil fuels
- Production
- Draught
- Human rights
- Global average temperature (SDG 13)
- Child labor
- Flooding
- Greenhouse effect
- Acidification
- Health (SDG 3)
- Decent working conditions (SDG 8)
- Work opportunities
- Transport
- Ecosystem services (SDG 15)
- Trade
- Jumping
- Monoculture
- Trade union rights
- Poverty (SDG 1)
- Eutrophication
- Agricultural land
- Localization factors
- Environmental toxins

Concepts given to the students as paper notes together with blank paper, pens, and glue



Authors

✉ **Lotta Dessen Jankell**
Stockholm University
Institutionen för ämnesdidaktik
106 91 Stockholm, Sweden
lotta.jankell@su.se

Dr. Patrik Johansson
Stockholm University
Institutionen för ämnesdidaktik
106 91 Stockholm, Sweden