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Both authors collaborated in the project "Research dialogue: System Earth" which was financed by the BMBF (German Federal Ministry of Education and Research) and carried out at the IPN. Its goal was to foster primary school students' system competences in the field of System Earth. The following article summarises results of an empirical study conducted in this context.

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System competence – Are elementary students able to deal with a biological system?

Abstract

The objective of this study was to elucidate elementary school students' (9-11 years of age) system competence. Starting from systems theory, a framework for system competence assessment was developed to analyse the relevant abilities. This framework describes the skills for system modelling and the ability to deal with system properties. In a pre/post-test-design 363 elementary school students were tested. Questionnaires and concept maps were applied to answer the research questions whether they are capable of creating a model of a given biological system and of recognizing specific system properties. The results indicate that elementary school students already show system competence in the tested domain "system stork". Their system organisation abilities were higher than their abilities to deal with system properties, such as predicting the consequences of changes or assessing complex effects in a system.

Theoretical background

Systems theory

In science epistemology, different ways to gain knowledge about the world can be distinguished. Two basic ones are the analytical and the systemic approach. In science class the analytical approach is very common. Complex structures are often separated into discrete elements (e.g. an organism into its organs) and the functions of these elements are analysed separately (e.g. the heart, the stomach or the lung). However, to understand the complexity of scientific systems such an analytical approach has to be accomplished by a systemic view (AAAS, 2009; KMK, 2005; NSC, 1999). The systemic view looks for the interactions between the discrete elements to explain the function of the whole (e.g. the interaction of the blood-system, the distribution of oxygen). Thus, the systemic view is a necessary epistemology in science. Hence, science education has to foster the understanding of systems. The difficulty in this demand is to describe clearly, what is meant by "fostering the understanding of systems". Therefore, we have to clarify the meaning of the relevant terms. With regard to the understanding of systems, in international literature the term "system thinking" is well-established. Though "system thinking" comprises more, the term "thinking" seems to apply only to the cognitive processes. Weinert (2001) has suggested the concept "competence" to emphasise the issue that educational goals should not be restricted to cognitive aspects. They should also refer to abilities and skills that are necessary for successful performance in domain-specific problem-solving and should in addition include competence-related motivational attitudes and volitional skills. We therefore prefer the term "system *competence*" when speaking about the abilities to deal with systems. Because Weinert's definition is quite comprehensive and difficult to operationalise on the whole, this paper focuses on skills and abilities necessary for system competence, but not on motivational attitudes and volitional skills.

System competence describes the abilities to identify and describe the structure of a system based on knowledge about that system. It also entails the abilities to understand its operating principles to enable management decisions. To explicate the meaning of "to identify and describe the system's structure" and "to understand its operating principles", we first analysed the basic characteristics of systems based on systems theory. In a second step, a framework for system competence assessment was derived therefrom.

System characteristics

System characteristics can be differentiated in two parts, system organisation and system properties.

System organisation

On a very general level, systems can be defined as "elements standing in interaction" (Bertalanffy, 1968). That means systems are composed of elements and the relationships between the elements. These relationships constitute the structure of a system. The structure of a system again determines its function (Bossel, 1987).

Systems are bordered entities. We define the scope of a system by identifying its boundary; this means choosing which entities are inside the system and which are part of the environment. In general, open and closed systems can be differentiated. Open systems exchange energy and matter with their environment. With regard to the elements, relationships and borders of a system, we focus on a system's structure or organisation. We abstract this part of a system's characteristics by the term "system organisation" (Table 1).

Table 1: System Characteristics.

	System characteristics	
System organisation	Elements	A system consists of system elements which interact with each other. These elements and their relationships comprise the structure of the system. The structure of the system determines the function.
	Relationships	
	Identity	A border separates the system from its environment.
System properties	Integrity/Emergence	Systems have particular properties which are not properties of the systems' elements (emergence). If we only use parts of the elements, then the system loses its integrity/some of these properties.
	Dynamics	A living system shows development within itself.
	Effects	In a system, different effects appear (e.g. side effects, repercussions, direct and indirect effects).

System properties

This part concerns the most common principles which explain the functions within a system. One of these characteristics is integrity, describing the phenomenon that if a person excludes or adds important parts to the system, it will lose its integrity and thereby its emergent property (see also Bertalanffy, 1968; Corning, 2002). This emergence means that parts work together in such a way that new and coherent structures or properties arise on a higher level of the system.

Complex biological systems have some more important characteristics. The first is dynamic interaction. It leads to development within a system. As a result, systems may change over time. A second characteristic of living systems is influenced by the complexity of these systems: in a complex system, different effects such as side effects, repercussion, direct and indirect effects, appear. These effects are part of the mechanism of a system to support a certain stage of stability, self-organisation and finally autopoiesis (cf. Maturana & Varela, 1980). Table 1 shows a summary of the most common characteristics of systems derived from systems theory.

A framework for understanding systems

To assess system competence, system characteristics have to be transferred in abilities and skills. In the following paragraph, we will give a description of how the components of system competence are derived from system characteristics and are operationalised in abilities that are observable in the performance of a person. As a consequence, system competence is a highly complex conglomerate of abilities.

Modelling: Understanding the structure of a system requires the ability to construct a simplified representation (model) of the system: First, relevant *elements and their relationships* have to be identified based on an analysis of the system. This requires domain-specific knowledge about the system. Second, depending on the observer's question, the borders have to be ascertained to determine the *identity* of the system. And finally, the elements, their relationships as well as the borders have to be presented in a verbal or pictorial model.

Dealing with system properties: The *integrity* of systems can be destroyed by adding or removing system components from the system. Therefore, a person has to distinguish the attributes of the system from the attributes of the elements to recognise that systems have particular properties which are not part of their elements. This also means recognizing that fragmentary systems lose their *emergence*.

Concerning the system characteristic *dynamics, s*ystem competence requires the ability to identify dynamic relationships in systems. Moreover, in dynamic systems, spatio-temporal distance may occur between two events. Thus, recognizing dynamics also means identifying the interaction between events and predicting the consequences of changes.

In systems different *effects occur*: if one element affects another element, it is a direct effect. If one element affects a third element via another element, this is called an indirect effect. Finally, an effect may retroact to its cause which is called a repercussion. System competence requires the ability to judge effects of different complexity in a system.

The framework for system competence assessment is composed of two parts: the first part contains the abilities which are related to the organisation of a system. These abilities can also be subsumed under the term "modelling". The second part includes the skills which refer to system properties. Table 2 summarises the abilities of system competence mentioned above. This framework describes system competence as several skills independent of disciplines and not devised for a special age group. This framework represents the basis for the following assessment of system competence.

Table 2: Framework of System Competence Assessment

	System characteristics	Abilities composing system competence	
System organisation	Structure of elements and their relationships	Modelling	to identify system elements and to associate them with each other, to organize system elements and their relationships in a reference framework
	Identity		to recognize and utilize system borders
System properties	Integrity/Emergence	Dealing with system properties	to distinguish the attributes of the system from the attributes of the elements
	Dynamics		to identify dynamic relationships to predict the consequences of changes
	Effects		to assess the effects in a system to identify and describe reactions

Research on assessing system competence

Empirical research has shown that students have difficulties in understanding systems. This research affects different aspects of system competence.

Modelling

Using and developing models is the part of system competence which seems to be relatively easy to learn. Working with models Ossimitz (2000) reports on high learning success of students grade 9 and 10 after instructions about dealing with systems. Also Verhoeff, Waarlo and Boersma (2008) revealed that systems' modelling enables upper-secondary students to acquire a coherent understanding of biological phenomena.

Dealing with system properties

Emergence: For example, students have difficulties in understanding emergent patterns which arise from interactions of subjects at lower levels of a system (e.g. the v-shaped pattern of geese in flight). Wilensky and Resnick (1999) showed confusion of levels as the source of many students' deep misunderstanding concerning patterns and phenomena in science. Moreover, Penner (2000) reports on students who anticipate a singular causal force that underlies an emergent phenomenon. Students also tend to ignore that removing components from a system effects the formation of the macro-level pattern.

Effects: There are also difficulties with detecting and understanding causal structures and effects within a system. As Grotzer (2003) showed, young students hold misconceptions about the nature of interrelatedness in ecosystems. This resembles an inability to deal with the specific types of causal patterns embedded in ecosystems. Seven to nine-year-olds typically reasoned about immediate effects and overlooked extended, indirect effects. More complex effects like feedback effects could not be identified by eleven to twelve-year-olds even in every-day systems like a pizzeria (cf. Evagorou, Korfiatis, Nicolaou & Constantinou, 2009).

Dynamics: Dynamics lead to reactions of the system which people cannot predict (e.g. Dörner, 1996). The difficulties of learners with dynamics in complex systems were described by Booth Sweeney & Sterman (2001). The students did not understand important features like stock, flow and time delay even in simple systems like a bathtub with water flowing in and draining out (e.g. Booth Sweeney & Sterman, 2001).

As outlined above there is empirical research about single parts of system competence. But there is hardly any empirical evidence whether, despite its complexity, science education can initiate system competence in young children (e.g. elementary school students). In our study we asked the following questions:

1. Are elementary school students able to create a model of a given system identifying the important elements and relationships? (system characteristic: modelling)
2. Are elementary school students able to recognise specific system characteristics?

2.1 Do elementary school students identify the attributes of the system and the elements? (system characteristic: integrity)

2.2 Do they identify dynamic relationships and predict the consequences of changes? (system characteristic: dynamics)

2.3 Do they assess the effects in a system and can they identify and describe reactions? (system characteristic: effects)

Methods

Design

We conducted a study with an enhanced pre-/post-test design. The system used in the intervention was "the white stork". The white stork is a huge impressive migratory bird breeding in northern Europe and hibernating in Africa. The "system white stork" includes the biotic and abiotic relationships between the white stork and its different forms of environments. Figure 1 shows the structure of the main study.

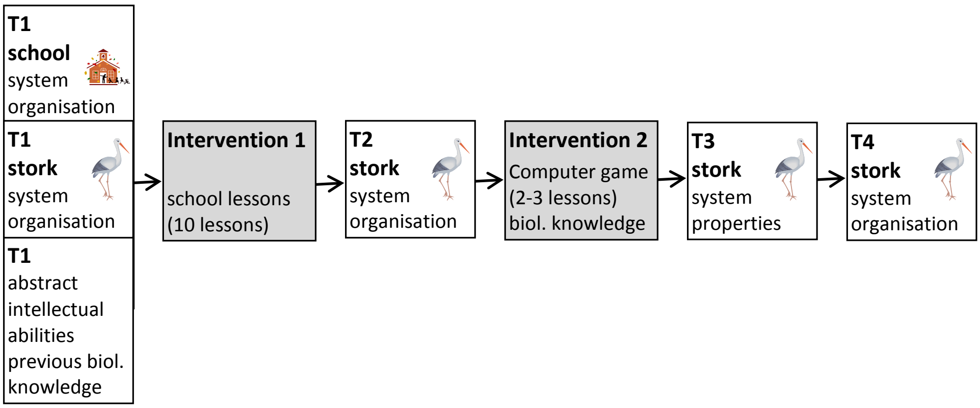

Figure 1: Overview of the study design - All tests (T: Test) lasted 45 minutes. T1 to T3 took place in direct succession, between T3 and T4 was a time-lag of 3-4 weeks.

In order to control other influences, we additionally measured students' gender, age, interest in the topic, prior knowledge of biology and abstract thinking ability.

Teaching Material

The teaching materials consisted of a teaching unit about the system "white stork" and an accompanying computer game, both developed by Sommer (2006). The teaching unit deals with the biotic and abiotic relationships of the white stork and its different environments, the white stork's hazard and its migration behaviour in comparison to other migratory birds. The computer game picks up and expands the information of the teaching unit in an interactive story. The teaching unit was divided into seven parts and was conceived for about 10 lessons. To standardise the instruction, the teaching unit contained materials and information for teachers and their students, including all practice sheets and experimental instructions. The teaching materials were tested in two elementary school classes and revised before being used in the intervention. The computer game was checked by 15 students.

Research instruments

Paper and pencil tests were developed according to the framework for system competence assessment (see Table 2). In addition, students' interests, some demographic data and students' prior knowledge of the "white stork" were assessed.

Pre-Test (T1)

First, a short test with five multiple-choice-items to measure the biological prior knowledge of the students about birds in general and the white stork in specific was presented. To assess the students' system organisation abilities (cp. Table 2), concept maps were used. In research on cognition, methods of concept mapping are discussed as tools to visualise cognitive structures (Bloom, 1995; Franco & Colvinvaux, 2000; Iuli & Helldén, 2004; Kinchin & Hay, 2000; Markham, Mintzes, & Jones, 1994; Peuckert, 1999; White & Gunstone, 1992). In a concept map, chunks of knowledge are represented as so-called propositions. A proposition is the smallest chunk which can be assessed as right or wrong and is defined as the smallest unit of knowledge which has a predicate and the arguments semantically associated with it (Opwis & Lüer, 1996).

As, according to Ossimitz (2000), system thinking, and thus system competence, is closely related to how knowledge is presented and, according to Gentner and Gentner (1983), system thinking (system competence) should lead to the construction of complex mental models, concept maps could be used to provide some information on the mental model. These mental models can be seen as a memory map of cognitive structures in which the system is represented. Externalizing the mental model in an expressed model can be assumed as an approximation of the invisible cognitive structures.

In literature there are different methods for drawing concept maps (İngeç, 2009; Mandl & Fischer, 2000; Ruiz-Primo, 2004; Ruiz-Primo & Shavelson, 1996; Safayeni, Derbentseva, & Canas, 2005; Shavelson, Lang & Lewin, 1993). In the present study, a form of concept map was chosen that was easy enough for young students and allowed the construction of a free model of the relationships between the students' ideas in a non-hierarchical network. The students could freely choose the elements and the type of connection. The connections between the elements could represent cause-and-effect relationships, super- and subordinated relationships (… is a …), temporal relationships (… and then …), local relationships (… in…) and final relationships (… in order to…).
The students first received an example of a concept map with the content of a soccer game to acquaint themselves with this method. In the pre-test (T1) the students were first asked to draw a concept map for the well-known system "school". We decided to include the system "school" in order to draw a comparison between the students' system competence in a more familiar system and a special biological system, and to identify the influence of prior knowledge and familiarity with a system on system competence.
The students were then invited to draw a concept map for the new system "white stork".

First post-test (T2)

The first post-test again assessed students' system organisation abilities by asking the students to draw a concept map for the system "white stork".

Second Post-test (T3)

The second post-test was applied primarily to measure students' abilities to deal with system properties. To test these abilities, the students had to answer several questions using an open response format. Several questions were formulated for every component of system property skills (Sommer, 2006; see Appendix).

Integrity: The first question to assess the component integrity dealt with the removal of an important element from the system. Students had to indicate what would happen if the nesting aids which are necessary for the white stork's nest-building were removed. The second question was related to an isolation of the elements in an artificial ecosystem: The students had to assess the consequences if existing elements of the system "white stork" no longer had a normal relation to each other.

Dynamics: The system competence components "to identify dynamic relationships" and "to predict the consequences of changes" addressed the dynamic component of system properties. To measure the skills required to identify dynamic relationships, two questions were used. The first question focused on the dynamics of the different demands of nutrition at different ages. In the second question, the dynamic aspect addressed the different behaviour of the white stork in its breeding area and in its wintering grounds. The students had to explain why the white stork stays in a limited area during the summer while flying from one region to another in winter. To answer this question, more specialised biological knowledge about the behaviour of the white stork was necessary.
The first question to predict the consequences of changes was a hypothetical problem in which the students had to predict the changes that would occur if the white stork produced the triple amount of eggs. The second question addressed the consequences of a lack of earthworms in spring, an important source of nutrition for storks.

Effects: The component "to assess different complex forms of effects in a system" was tested with three questions. Focusing a direct effect in a system, the students first had to decide if the electric power transmission lines had an influence on the white stork. The second problem contained an indirect effect on a system. It dealt with the utilization of land for farming and its consequences for the habitat and nutrition of the white stork. The third question tested whether the students could assess a spatio-temporal distance between cause and effect in a system by discussing the influence of the lack of rain during the rainy season in Africa, although the white stork would arrive a few months later.

Third post test (T4)

The third post test (T4) was a follow up-test after three - four weeks. It contained the same content as the first post test (T2).

Subjects

The sample of the study included 363 students (159 girls and 186 boys) from elementary schools of the third and fourth grade. The students came from 24 school classes in 22 different schools. The schools are located in rural and urban regions in Northern Germany. The students were between 8 and 12 years old. In Germany, all children attend the same elementary schools, so the children had various socio-economic backgrounds.

Data analysis

Concept maps for testing system organisation abilities

Concept maps can be qualitatively and quantitatively analyzed. For quantitative analyses, graph-theoretical dimensions are described by Nicoll, Francisco and Nakhleh, 2001; Novak and Gowin (1984); Ossimitz (2000) and Yin, Vanides, Ruiz-Primo, Ayala and Shavelson (2005). They all assess the number of elements (also named nodes) and arrows (also named edges) used in a concept map in order to compute several indices. This quantitative analysis provides a basis for qualitative interpretations of the concept maps. The quantitative analysis in this study addressed two indices: the interconnectedness index, and the structure index. The interconnectedness index represents the integration of elements into the adjacent concepts and the number of arrows drawn. It is computed by two times the number of arrows divided by the number of elements (Ossimitz, 2000). The structure index describes the form of the complete concept map. With regard to the structure, we distinguish between different forms in increasing complexity from unconnected elements via chains and cycles through to complex networks similar to Yin et al. (2005). A network is defined as the minimum number of five elements that are connected in a non-linear matter. So, a network comprises at minimum two ramified or converged nodes. All data were judged by two independent persons to prove the reliability (Kappa = .81).

Questions for testing the abilities to deal with system properties

The students' abilities to deal with system properties were tested with questions in an open format. All answers were categorised according to the understanding of the specific system property: no understanding of the question, no recognizing of effects or consequences, describing unspecific effects within the system white stork, describing specific effects with focus to the features of the question. An example of scoring the answer of dealing with dynamics concerns the question what would happen if the white stork produces the triple number of eggs. If students only mentioned that the number of white storks would increase, this was categorised as an unspecific effect. If students additionally answered that a higher number of storks would lead to a lack of food and in the long run the white stork population would decrease again, they describe a feedback loop and score the highest category. Two independent raters established the categorization. For further analyses, all correctly answered questions describing a specific effect in the system were rated with one point and summed up to a total score for dealing with system properties.

Results

Preliminary Analysis

A great variance between the different classes and schools exists but that is quite common for a field study. But, in subsequent analyses, the classes were combined to look for general tendencies that occur despite the variation between the classes. In our theoretical framework for system competence (see Table 2) we distinguish between system organisation abilities and abilities to deal with system properties. We used a main component analysis with VARIMAX rotation and two factors preset to examine whether the two theoretically separate domains can be distinguished from each other empirically. We included the interconnectedness index for the system "white stork" and the system "school" at each time of testing and the total score for dealing with system properties for the system "white stork" and the system "school". We verified the two factors, one for modelling systems and one for dealing with system properties. The only variable that had high loadings on both factors was the interconnectedness index for system stork in the pre-test. Both factors cleared a total of 46.1% (26.6% and 19.5%) of variance.

We analysed the relationships between biological prior knowledge and system competence. The biological prior knowledge correlates moderately but significantly with the interconnectedness index ($r = .26$, $p < .001$), the structure index ($r = .28$, $p < .001$) and the total score for dealing with system properties ($r = .30$, $p < .001$). For further analyses we transferred all these variables into new dichotomous scores by using median splits and calculated cross tables (s. Table 3).

The standardised residuals in the cross tables revealed that both, the structure index and the score for dealing with system properties, were significant (>|2|) for students with limited biological prior knowledge. On the one hand, more students with limited prior knowledge draw less complex concept maps and fewer students draw high complex concept maps than expected. On the other

Table 3: Cross-tables of previous biological knowledge, structure index, interconnectedness index & the total score for dealing with system properties

			Interconnectedness index		Structure index		Score for dealing with system properties	
			Low	High	Low	High	Low	High
Previous biological knowledge	Low	Observed	49	46	49	22	45	31
		Expected	44,3	50,7	31,7	39,3	30,5	45,5
		Stand. residuals	0,7	-0,7	3,1*	-2.8*	2,6*	-2,2*
	High	Observed	96	120	67	122	62	129
		Expected	100,7	115,3	84,3	104,7	76,5	114,5
		Stand. residuals	-0,5	0,4	-1,9	1,7	-1,7	1,4

* Residuals greater than |2| indicate that observed frequencies are higher (lower) than expected.

hand, students with sufficient prior knowledge did not automatically draw high complex structured concept maps. The same pattern was revealed for the relationship between previous acquired biological knowledge and the score for dealing with system properties, but not for the interconnectedness index.

System organisation abilities

Interconnectedness of concept maps

The interconnectedness shows how closely the elements in the concept maps are connected. The mean value for each test part is presented in Figure 2.

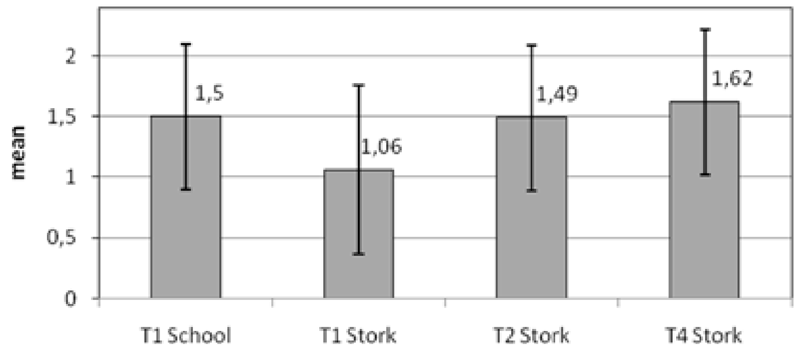

Figure 2: System organisation abilities: comparison of the means and standard deviations of the interconnectedness index between the test parts.

In the pre-test (T1), the students received highest scores on the interconnectedness index for the system “school”. In the same pre-test (T1), they showed significantly lower scores for the system “white stork” concept map (T(281) = 10.5, p<.001). This difference is attributed to the available knowledge of the systems. After the lessons at T2 the interconnectedness score was significantly higher (T(219) = -7.1, p<.001). Between T2 and T4 the students played the computer game. This had no further influence on the interconnectedness score (T(136) = -1.9, ns.).

Structure of the concept maps

Concerning the structure of the concept maps, we distinguished between different categories of increasing complexity. Figure 3 shows the frequency change of the concept map's different structures for all tests.

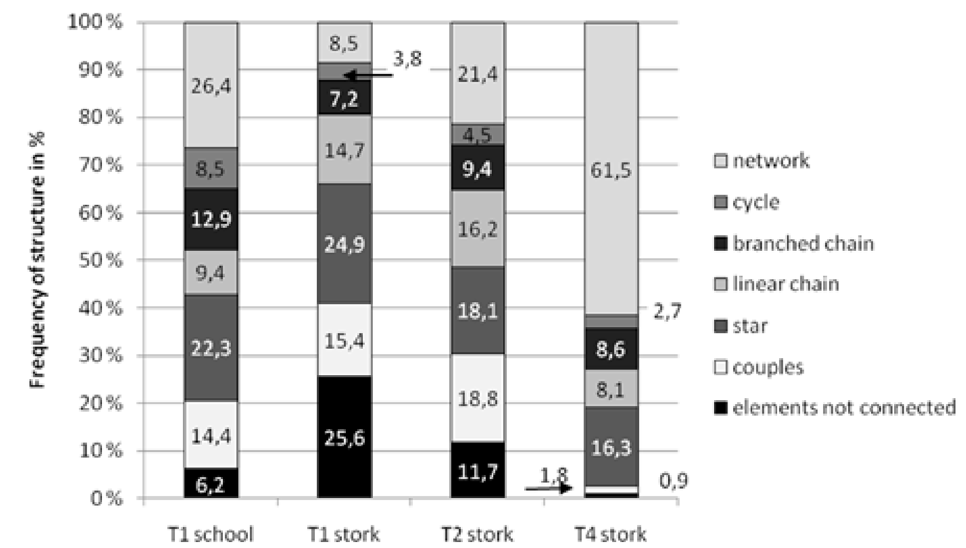

Figure 3: System organisation abilities: comparison of the structure of concept maps between the test parts.

In the pre-test (T1) for the system "school", only 6.2% of the children could not connect their elements in the concept map, but 26.4% drew a network. Most students drew a concept map for the first time. At the same time (T1), 25.6% of the students could not connect the elements when drawing a concept map about the system "white stork" and only 8.5% drew a network. The statistical analysis with the Wilcoxon signed rank test showed that the difference between the test parts is significant ($Z = -9.3$, $p<.001$). The values between T1"stork" and T2 "stork" changed. At T2 more children drew a network (21.4%) and fewer children could not connect their elements (11.7%). The statistical difference between T1 "stork" and T2 "stork" is also significant ($Z = 6.6$, $p<.001$). After the computer game (T4 "stork"), only 0.9% of the children could not connect the elements, and with 61.5%, significantly more students could draw a network ($Z = 8.6$, $p<.001$). Figure 4 shows an example of a concept map, scored as a network.

Abilities to deal with system properties

Integrity: The ability to distinguish between the attributes of the system and the elements was tested with three questions in T3. The first question (I1) deals with the impact of adding important elements to a system. A high number of the students (86.3%) answered this question by detailing specific changes for the system. The second question (I2) deals with the removal of important elements from the system, here with the removal of the nesting aids. Simple consequences such as "It no longer has a place where to lay its eggs in" are described by 41% of the students. Altogether 55.5% of the students gave answers which were judged as specific consequences. These answers described more complex details such as "The white stork couldn't find any nesting site and so it couldn't lay eggs and so it will die out". The third question (I3) concerns the function of isolated parts of the system "white stork". This question should establish whether the children understand the concept of emergence. This was not as easy to understand as the preceding questions: while 8.2% of the children did not understand the question, 13.1% of the children believed that the iso-

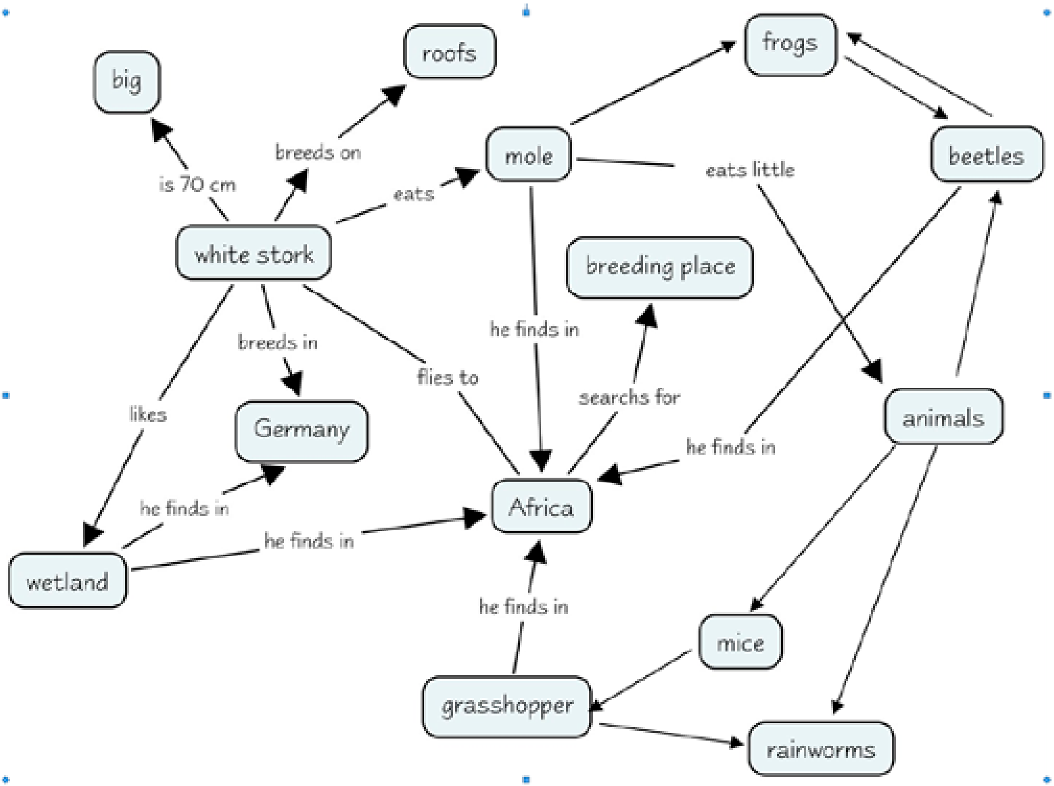

Figure 4: Example of a concept map from a ten-year-old student, scored as a network (T4).

lated parts of a system act like the parts integrated in a system. Almost half of the students (46.3%) mentioned only general consequences like "The white stork isn't doing very well" and only 32.4% of the students described specific consequences of the isolation.
These results show that the majority of the children know that the isolated elements do not have the same function as the integrated parts, but they cannot state the reason for this (figure 5). Hence, only a third of the children took the ecological relationships hidden in the question into consideration.

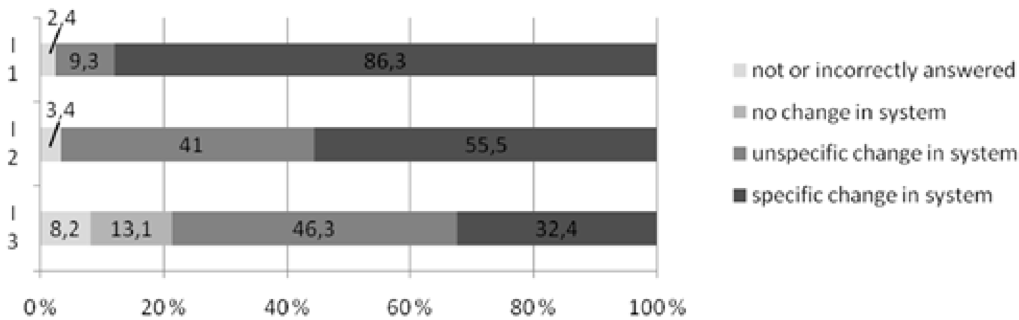

Figure 5: Abilities to deal with system properties: integrity.

Dynamics: Concerning the first question about identifying dynamic relationships (D1), 52.8% of the students recognised the dynamics of different demands on nutrition at different ages, whereas in the second question (D2) only 13.5% of the students explained dynamic processes concerning the different behaviour of the white stork in its breeding area and in its wintering grounds (figure 6).

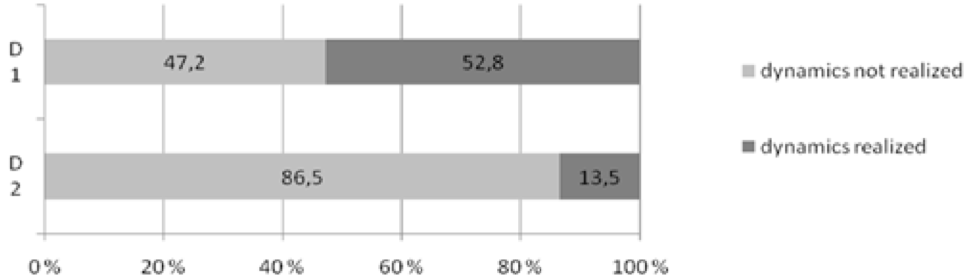

Figure 6: Abilities to deal with system properties: dynamics.

Predicting consequences relating to changes was also operationalised by two questions. The hypothetical problem (D3) in which the students had to predict the changes that would occur if the white stork produced triple the number of eggs was answered by providing the specific consequences for the system by 56.6% of the students (figure 7). A further 10% of the children spontaneously described a feedback loop. They argued that it would not come to an increased stork population if the storks produced triple the number of eggs because the storks would not find enough to eat and could not find enough breeding places. The second question (D4) asked for the consequences of the lack of earthworms in spring. Concerning this lack of nutrition a large number of children (38.2%) mentioned no consequences for the white stork. The analysis of the answers shows that the students argued with a large range of prey species, but they did not consider that there is a seasonally affected shift. While 20.1% of the students provided unspecific consequences, a further 34.1% were able to predict specific consequences for the white stork.

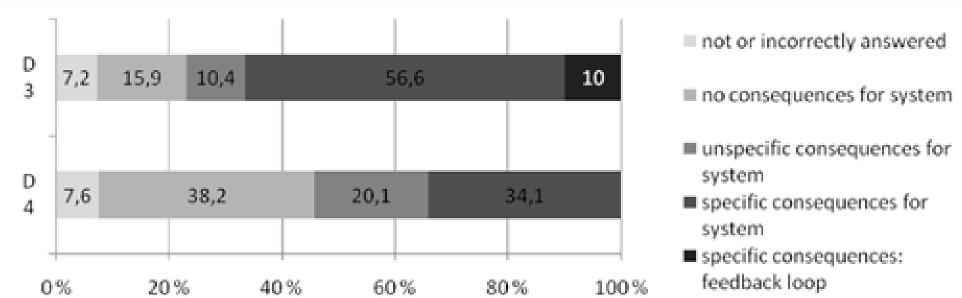

Figure 7: Abilities to deal with system properties: consequences of changes.

Effects: The system competence to assess the effects in a system was tested by three different types of effects. The question about the electric power transmission lines (E1) tests whether the students can assess a direct effect in a system. A large number of the students (82.6%) reasoned that there is an influence and explained correctly that the stork can be harmed by the electric power transmission lines. An indirect effect is tested with the second question (E2) about the conversion of marshy land for agriculture. Most students (79%) correctly described that land manipulation changes the living conditions of the storks' prey and the white stork cannot find enough food.

The third question (E3) concerns a spatio-temporal distance between cause and effect in a system. While 21.4% of the students detected no causal connection, 22.5% of the students described an unspecific connection. An additional 24.0% mentioned a specific connection with the white stork. Only 22.9% of the children fully recognised this relationship. These children argued that the rain which usually falls several months before the white stork arrives in Africa is necessary for plant growth. These plants are eaten by insects and other animals, which are finally eaten by the stork.

These results show that students are able to assess direct and even indirect effects in a system (figure 8). But a spatio-temporal distance between cause and effect such as rainfall in Africa and the white storks' chances of survival are obviously quite difficult to understand for the majority of elementary school students.

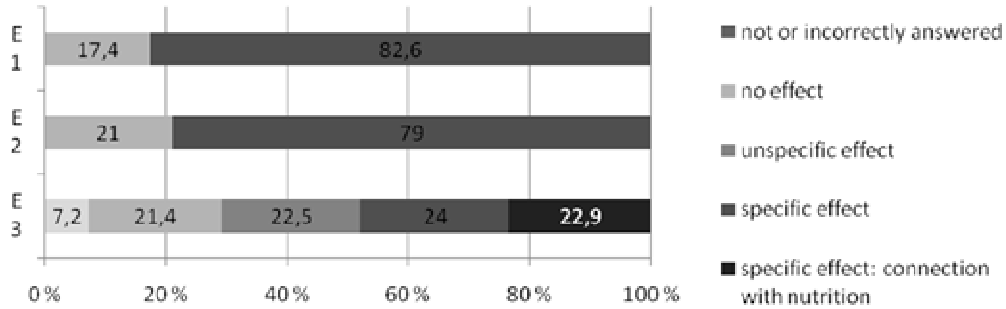

Figure 8: Abilities to deal with system properties: effects.

Discussion

This study examined the system competence of elementary school students and pursued two research questions. The first one dealt with the abilities of younger students to build models of a given system and the second examines the abilities to recognise specific system characteristics.

Abilities to build models of a system

In order to build a model of a system, it is necessary to identify the relevant elements of a system and to connect them with relationships. These abilities were tested quantitatively by two indices: the interconnectedness and the structure of the concept maps. As the results show, the structure index of the concept maps for the system "white stork" increased significantly from T1 to T4, whereas the interconnectedness increased from T1 to T3 and remained on a relatively high level. There seems to be no more potential for further increase after the second intervention. The static of the interconnectedness index between T2 and T4 may result from the fact that concept maps become more confusing when interconnectedness grows. We can conclude that elementary school students' system organisation abilities in this particular system are well-established. We conducted an additional content analysis of the propositions in the concept maps and discovered that there was not only a quantitative but also a qualitative increase in the concept maps. It was rather difficult to decide whether a proposition is essential for a system or not (Klieme and Maichle (1994) as well as Ossimitz (2000) consider it to be "hardly possible" to find objective criteria for this decision). Thus, we analyzed the distribution of the propositions across content categories. In T1, most propositions were found in categories which refer to general biological knowledge about the white stork, such as its food, appearance and reproduction. A significant increase was found in categories which require special knowledge about the white stork, such as its breeding place, migration, habitat and risks. These shifts correspond with the contents of the school lessons.

Interpreting the validity of our quantitative method of using the concept maps to assess students' abilities to model systems, it is difficult to find comparable results from other studies, since there are plenty of possibilities for drawing concept maps (overviews e.g. in McClure, Sonak, & Suen, 1999), the study by Ossimitz (2000) is most similar to the methods chosen. In his study, older students (aged 15 to 19) drew cause-and-effects diagrams. These students yielded interconnectedness indices between 1.02 and 1.27, with a mean of 1.45. In contrast, the students in our study could freely choose the type of relationship. The indices for the interconnectedness of the concept maps for the system "white stork" increased from an initial 1.06 in T1 to 1.62 relationships per element in T4. Due to the different conditions, a direct comparison between the results can only be tentative, but it can still give an idea of the magnitude.

Another aspect of validity concerns the method for assessing system organisation. As the structure of the concept maps increases strongly from simple to complex maps, it can be assumed that increased practice with concept mapping had a certain influence. But this result must have other causes, too: The children drew a concept map in T1 for the first time. These concept maps for the system "school" contained a high percentage of complex structures. At the same time, but for the system "white stork", the percentage of simple structures in the concept maps was significantly higher and the percentage of complex structures was significantly lower. In this part of the test, the children had a lot of knowledge about the system "school", but little knowledge about the system "white stork". This indicates that practice in concept mapping could not be the only reason for the increase, and that knowledge about a system must be an important precondition for developing a model of the system.

The results concerning the role of biological prior knowledge shows that students who drew a complex model of the system stork scored high also in our test of biological prior knowledge, whereas students scoring high in the knowledge test did not necessarily draw complex models. For the interconnectedness index these relationships could not be verified: further research on the issue has to be provided. Despite this, these indications suggest that domain-specific knowledge is a necessary, but not sufficient pre-condition for system competence. To describe a relationship between the food supply in spring and the breeding success of the white stork in summer, it is necessary to know that the white stork lives mainly on earthworms in spring. If this particular knowledge is not available, you cannot describe the relationship between the amount of earthworms and the breeding success of the white stork. Hence, system competence seems to need domain-specific knowledge about the particular system. General biological knowledge may lead to a conceptual understanding of biological systems in general, but it is probably not sufficient to form a systemic view of a particular system. In future research, we plan to identify the part of the students' performance that can be explained by the mere accumulation of domain-specific knowledge as well as the part of the performance that can be explained by the development of system competence (Hipkins, Bull & Joyce, 2008; Ossimitz, 2000).

To summarise the results for organisation of the systems school and white stork, we showed that the knowledge available of a system has a great influence on the modelling ability. The lessons about the white stork considerably influenced this ability. In addition, it is remarkable that the elementary school students had a relatively high level of success in this part of system competence. These results align with outcomes of other studies, e.g. older students' fast progress in modelling (Klieme & Maichle, 1994; Ossimitz, 2000). They are also consistent with the experience gained in studies of elementary school students on the method of concept mapping (Treinies & Einsiedler, 1993). To sum up, our results support the findings in literature that building or using models is crucial for the development of system thinking or system competence, respectively (Ossimitz, 2000; Westra et al., 2008).

Abilities to recognise specific system characteristics

The abilities tested in this part of the questionnaire concern three system properties: integrity, dynamics, and effects.

Integrity/Emergence: Obviously there is a difference between understanding the loss of systems integrity and the understanding of emergence. Describing the consequences of deleting important parts of the system like the nest aids, the students revealed their understanding of systems integrity. Emergence seems to be a sophisticated characteristic of systems. It was difficult for students to understand that a system, decomposed in isolated parts, could no longer act like a complete system. Difficulties in understanding emergent patterns which arise from interactions of subjects at lower levels were also referred by Wilensky and Resnick (1999). These difficulties may result from the fact that younger students are not able to change between different levels of a system. But further research has to be conducted to verify this assumption.

Dynamics: The results concerning dynamic aspects show that students were not able to correctly answer questions which required specific biological knowledge about the white stork. Only in the questions requiring general biological knowledge the children were able to recognise dynamic relationships. Difficulties with identifying dynamic relationships within a system are also reported by Assaraf and Orion (2005). Although most of their students improved understanding of dynamics during the learning process, 50% of them still retained a non-scientific static model of the investigated system.

Effects: Whereas direct and indirect effects could be assessed by the majority of the children in our study, Evagorou et al. (2009) report on difficulties of children of the same age with indirect effects. The familiarity with the context and the resulting knowledge about the system may constitute this difference, but the difficulties reported by Evagorou occur even in everyday systems. Obviously, understanding a spatio-temporal distance between cause and effect is too complex. The relevant question was only answered correctly by a quarter of the students. Apparently, the abilities of elementary school students are restricted here to a lower level of system competence. As our results show, other factors apart from knowledge have to limit the abilities to recognise system characteristics. We cannot decide whether these limitations are to be ascribed either to a general cognitive restriction depending on age or to the special system that was tested here, or to the lack of training in system competence. Further studies are needed to answer these issues.

Summarizing conclusions for instruction

One of the goals of educational research is to make valid and generalisable statements on the basis of the results obtained from an examined group. There are two complementary approaches to accomplish this goal. On the one hand, experimental design can be used to trace back effects to controlled influences. On the other hand, investigating realistic school settings offers "ecologically valid" statements which are true for school reality with its multitude of practically uncontrollable influences. In this study, we intended to make ecologically valid statements based on a wide empirical basis involving 27 school classes randomly selected out of elementary schools in northern Germany. In addition, we aimed at controlling the influence of the teachers by providing teaching material. As we could see from the differences between classes, the teachers had had an influence, which, however, was not systematic. The effects of the treatment are observable beyond the natural heterogeneity and they are generalisable for further interpretation. Nevertheless, we started to extend research about the teachers influence on students' system competence.

The abilities to deal with the system "white stork" show that elementary school students are able to acquire system competence on a basic level. As other research sources confirm (e.g. Ossimitz, 2001), modelling is an important condition for understanding systems. Since understanding the organization of a system is basic for understanding a system's properties, it makes sense to foster system modelling in particular. Therefore, concept mapping is an applicable method. It is a possibility to model a system in a way that is easy to learn even for younger students. As students' difficulties in dealing with system properties are more pronounced when systems become more complex, fostering primary school students' system competence should begin with basic abilities, e.g. fostering the understanding of direct and indirect effects.

The described results provide first indications that a systemic view can be established in the elementary school curriculum. In Germany, there is a tendency to improve this systemic view in the curricula of the secondary schools. To gain a deeper understanding of systems, system competence should thus be enhanced in elementary school. First attempts to introduce system competence in elementary school in the context of System Earth education were successful (Lücken & Sommer, in preparation).

This study shows that there are quantitative and qualitative changes in the students' system competence during the learning process. These changes are influenced by the knowledge which the students gained during the lessons. Biological content knowledge is necessary for systemic competence, but no guarantee for the development of a high level of system competence. In other words, basic knowledge about the biological content is necessary, but not sufficient. System competence requires content knowledge as well as abilities in dealing with systems. This has an influence on instructions to be given at school: Without knowledge about the facts in a system, it is not possible to grasp complex relationships or to establish connections between individual facts. However, it is also important to provide students with more methodological and abstract knowledge about systems and the way they work. Hipkins, Bull and Joyce (2008) suggested that both contextual and conceptual knowledge is needed for understanding systems. Hence, fostering system competence in schools means teaching content knowledge as well as providing students with the opportunity to deal with systems in different contexts.

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Appendix

System characteristic	Questions in the second post-test (T3)
Integrity	Imagine people would remove all white stork nests from their roofs and take all nesting aids down. Which consequences would have this for the white stork? In an experiment scientists put all the necessary things for the white stork into a big room: a nest, earthworms in a box, much beetle in another box, water in a bucket and so on. What do you think would happen with the white stork in this room after six month? Would it look like a scene from nature?
Dynamics	Do baby white storks eat the same food as older or grown-up white storks? Explain! In the breeding area white storks always stay in the same place, during hibernation they fly from one area to another. Right or wrong? Explain! Imagine a white stork would produce three times the number of eggs. What would happen? Explain all effects, also the effects not directly concerning the stork! Once in spring there was a lack of earthworms. How did this affect the white stork?
Effects	In former times there were no electric power transmission lines. Now they are everywhere and bring electricity to peoples' houses. This has no influence on the white stork. Right or wrong? Explain! Germans want to use all the land for farming. Therefore, they drain marshy land and reroute rivulets in channels to avoid flooding. This does not cause problems for the white stork. Right or wrong? Explain! Sometimes it rains very little in the rainy season in Africa and in some areas there is no rain at all. A few months later the white stork arrives in Africa. Is it important for the white stork if it has rained during the summer?