Educational Research

Conceptual Change Through Changing the Process of Comparison

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Classification can serve as a tool for conceptualising ideas about vertebrates. Training enhances classification skills as well as sharpening concepts. The method described in this paper is based on the 'hybrid-model' of comparison that proposes two independently working processes: associative and theory-based. The two interact during a classification process. The development of classification skills helps pupils to construct their own concepts and to reduce misconceptions. It is proposed that the shift from similarity-based classification to theory-classification promotes the conceptual change of concepts about vertebrates. This study investigates the effectiveness of classification training in three fifth grade classes. It examines how classification skills influence the construction of vertebrate concepts. A test instrument was developed to obtain results about the use of the two classification processes in the classroom. The results confirm that pupils changed from similarity- to theory-based classification and that a change of vertebrate concepts took place.

Introduction

Psychologists consider classification to be an important aspect of the cognitive process because pupils acquire the ability of constructing concepts that are integrated and memorised in the semantic memory. These concepts are important elements of knowledge.

Classification of organisms remains very difficult for fifth graders. The preconcepts of living organisms pupils have constructed in everyday life do not always correspond to biological ones. A number of investigations have demonstrated this lack of taxonomic knowledge (Braund, 1991; Kattmann, 1996; Ryman, 1974). The common idea that penguins, whales and sea-lions are fish reveals a classification based on habitat and locomotion criteria. The problem is that such misconceptions are resistant to change (Duit, 2000; Kattmann, 1992). Instead of using learnt ideas, people continue applying their original concepts.

This article asks how to help pupils rebuild their knowledge about vertebrate concepts in such a way that their conceptual understanding fits the scientific evidence. It proposes a new approach to teaching the *Classification of Vertebrates.* This approach relies on the theory of the hybrid model of classification and on conceptual change theory.

The hybrid model of comparison

Every classification is based on a comparison. The cognitive process of comparison is considered as a construct of two parts, the associative aspect and the explanatory aspect (Hampton, 1998; Keil, Smith, Simons and Levin, 1998; Lakoff, 1990; Rips, 1989; Sloman and Rips, 1998). It is called the 'hybrid model'.

The **associative aspect** matches many attributes of two or more objects, or of a category, with the object to be classified. It is based on similarity judgements. This article uses the term 'similarity' for this automatic working process of naming the sameness that two objects share. This kind of classification is very common in everyday life. Similarity works best when there are clear categorical features and a basic level of shared features (Hampton, 1998). A problem with this process lies in the fact that the evaluation of similarity between objects changes depending on the situation. For many instances of classification – such as highly abstract levels or the fuzzy boundaries of categories – comparison cannot be reduced to similarity.

The **explanatory aspect** represents the rule-based process. Rules can be very different, for example logical, normative or descriptive. They are not compatible with the associative aspect and work independently of similarity. Rules determine the context of similarity and select the similarities that are needed. This aspect works in domains of weak similarity or when the properties of objects correspond to two categories (Sloman and Rips, 1998). Rule-based classification is an alternative in cases without perceivable similarities.

Both aspects are active during a classification process and they interact (Sloman and Rips, 1998). A rule-based inference and selection process takes more time than similarity judgments (Kroger, Keith and Hummel, 2004; Sloman and Rips, 1998). While in everyday situations, only the faster similarity-based process is usually at work, both similarity- and rule-based processes are involved in the correct determination of an animal concept (Smith, Palatano and Jonides, 1998).

How do these comparison processes apply to the classification of vertebrates? The classification of a penguin, for example, cannot be based on the typical but non-defining attribute '*flying*'; instead, inference processes about defining attributes are necessary. These operations are performed by the explanatory aspect. The following illustration shows how the two parts of the classification process work together.

For selection criteria to match attributes, pupils take advantage of the explanatory aspect during the classification process. They choose a taxonomic-related criterion for listing

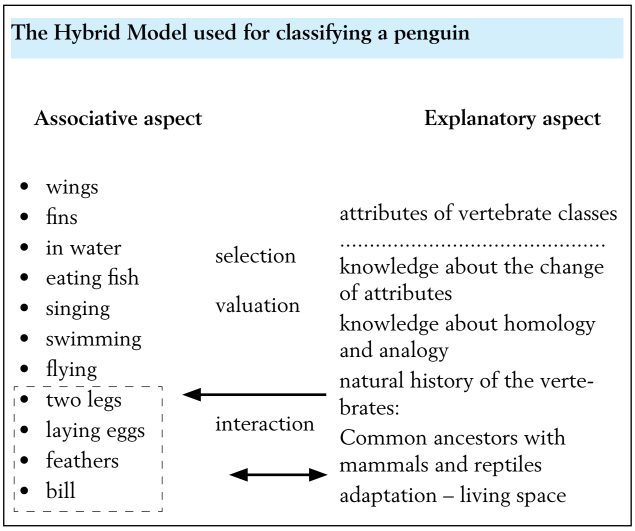


Figure 1. Classifying the penguin as a two part procedure.

similarities and differences. In this process one can differ three components: the criterion, the animal species and the animal category (Janich, 1993). Otherwise, the perception of similarity switches between different criteria such as between adaptation-related or taxonomic-related aspects. This unsystematic use of criteria was investigated by several researchers (Hammann and Bayrhuber, 2002; Kattmann, 1996; Ryman, 1974).

Learning difficulties in conceptualising vertebrates

Similarity in biology

The use of similarity-based classification may provoke fundamental errors in classifying living objects. If the classification is based on the perceptual feature '*streamlined*', a penguin as well as a whale is grouped into the class of fish. This misconceptualisation is due to the fact that in everyday life people define what is similar between two objects by a very subjective view depending on the context (Kinchin, 2000). According to Eichberg, this type of comparison, called *analogue comparison*, depends mainly on one or two isolated common properties (Eichberg, 1972). The analogue type of comparison cannot reveal a common internal structure and consequently not the classification of vertebrates. Hence, misconceptions might grow.

It is important to differentiate between homology and analogy in the classification of vertebrates. Homology means the commonality of internal structures due to the common origin of living organisms, while analogy is defined by external similarity attributed to the same habitat without any taxonomic relation (Remane, 1956). The classification of vertebrates involves homologies. Homologies are explained by evolution. If pupils determine the relevant properties relying on the evolutionary theory, they will be able to make classifications independently of similarity-based judgements. Evolutionary knowledge in terms of the history of nature, the change in species and the differentiation between analogy and homology may govern the selection of the associative listed features. In this sense, theoretical knowledge could improve classification skills.

Classification at different levels of abstraction

One should be aware of the fact that comparisons based on similarity give good results at basic levels of abstraction because the specimens in this concrete category reveal many common surface properties. Thus animals such as donkeys and horses are easily comparable on the basis of perceptual features.

The more abstract the representation, the less dependent the classification is on similarity. The abstraction increases over family, order, class up to subphylum. Higher abstract taxonomic groups do not show common external features. In imaging an eel, an elephant or a puffin one will hardly find external resemblances for being part of the category '*vertebrate*'.

Conceptual change theory

Following Posner *et al*, the conceptual change theory is based on the assumption that pupils bring to the classroom prior knowledge that is not always consistent with a scientific view of phenomena. The conceptual change theory uses the term *misconception* if the concept constructed in everyday situations differs from the scientific point of view (Posner, 1982). In this context, Ellis emphasises that prior strategies like comparison patterns may lead to misconceptions (Ellis, 2007). The common suggestions that penguins, whales, sealions are fish reveal such misconceptions. Other preconceptions have to be extended to get closer to the scientific point of view. Instead of using the learned conceptions, people go on applying the concepts they first learned as one can recognise in the sentence 'the eel and fish'. One reason is due to the fact that the basic concepts we first learn are deeply integrated in our mental representation and difficult to change (Lakoff and Johnson, 2003). Kinchin recommends that one differentiate clearly between conceptual change and contextual change and emphasises the need to be aware of the possibility that pupils switch in different situations (school/everyday) between competing conceptual models (Kinchin, 2000).

According to Posner, four conditions play a crucial role for conceptual change:

- first, the learning situation should bring up the misconceptions and create discrepancies between old convictions and scientific view
- second, the new knowledge must be intelligible, meaning that pupils must understand the scientific model or principle. The history of nature is viewed as an appropriate explanation of the vertebrate taxonomy
- the third condition is plausibility. The new concept must be reasonable for pupils. In the case of vertebrates, the theory of descent can better explain the taxonomic system than a similarity-based classification (Baalmann, 1998; Hammann and Bayrhuber, 2003; Janich and Weingarten, 1999; Kattmann, 1995)
- Fourth, new arguments should be useful for daily life (Posner, 1982).

The conceptual change idea assumes active learners who reconstruct their naive conceptions (Duit, 1996; Posner, 1982). In the classroom, pupils should be given the opportunity of reconstructing their existing conceptual understanding of vertebrates. This paper assumes that the classification method is the appropriate learning activity for conceptualising vertebrates. Understanding vertebrate concepts requires a change in the method of comparison.

The research question

This study assumes that an enhancement of classification abilities combined with nature history information fosters conceptual change of vertebrate conceptions. If the classification method is enlarged by a rule-based process, pupils are able to use homology-oriented criteria instead of analogy-related ones.

So, the first hypothesis proposes that an improvement in the method of classification leads to a better conceptualisation of vertebrates.

The second hypothesis proposes that natural history of the vertebrates as explicit subject matter supports the explanatory aspect of the classification process.

Design of the study

Sample and treatment

An intervention with three fifth grade classes (two experimental and one control group, n = 76) was performed. The first experimental group improved their classification skills and learned about the natural history of vertebrates; the second experimental group improved its classification skills; and the third class was the control group that received traditional lessons without explicit classification training and without natural history elements:

- Experimental I (n=26): Classification training + learning about the history of nature
- Experimental II (n=26): Classification training
- Control group (n=24): Traditional learning: sequential presentation of typical examples of different vertebrate classes

The introduction to classification represented the main part of the teaching unit on vertebrates for groups I and II. They used animal cards to classify species into vertebrate classes and to represent the variability of species within one vertebrate class. The sequence opened up many activities for self-guided learning.

First step: The introduction to the vertebrates started with a classification of the diversity of animals. Examples such as skeletons and animal models from the school collection were used. Pupils sought criteria for comparison purposes and found criteria like living space, legs/no-legs and so on.

Second step: Pairs of students discovered morphological resemblances and differences between two animal species. These examples came from different vertebrate classes and were fairly different in their exterior. Each pair worked on different vertebrates. At the end of this step, class concepts of vertebrates were established derived from experience with many examples.

Third Step: Group I only
The teacher and pupils retraced the development and change of features, species and phylae and elaborated the natural history of vertebrates.

Fourth Step: Students worked in teams. Animal cards served as the main teaching material at this stage. Pupils analysed more than 50 different animal cards. The front of the card showed a picture and the name of the animal, the back described its characteristics. Pupils looked for the relevant properties to classify the animals, evaluating and selecting the given information. The working groups designed a poster for one of the five vertebrate classes and presented to the rest of the class. They pinned the animal pictures on the poster. This was one way to recognise the variety of species within one natural group (Wasmann-Frahm, 2006a, 2006b).

Method and instruments

Pre-, post- and follow up- tests were designed and the results statistically evaluated.

A two-part classification test was developed to obtain results on the use of similarity-based and rule-based comparison as well as on animal concepts. The test consisted of three animal cards with a prototype organism – the stork – and two cards with untypical animals such as the whale and the penguin. The animal cards were identical for the pre- and post-test. Six months later the test procedure was repeated, with other species, however, shown on the cards - a sealion, a stingray, and an orca. This was necessary to avoid learning and fatigue effects. The pupils got two different classification cards:

- The first card (picture card) testing the spontaneous classification through the associative aspect
- The second card (information card) for testing classification by both aspects

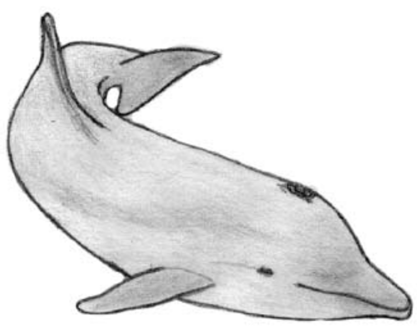
First, the pupils noted their associative ideas when considering the animal picture.

Second, they had to classify the animals. Classification immediately after noting associations stimulates the automatic part of the classification process, the so-called similarity-based classification.

As I was interested in their spontaneous responses I limited the time to four minutes for the three animal cards. At the end of four minutes the animal cards were collected.

The second card comprised textual information about the

Figure 2. Test material: animal card with picture; initial classification.



Dolphin
Note your first ideas when you see this animal.

Group the dolphin into a vertebrate class

fish	amphibian	reptile	bird	mammal

Do you know this animal? Yes ☐ No ☐

Dolphin/*Tursiops tuncatus*

Dolphins are very intelligent. They can communicate very well. They even recognise how humans feel.

The form of their body is well adapted to live in water. They have to come up to the water surface for respiration. Dolphins are viviparous animals and bring forth young ones. At birth the female helps its calf to the surface to get its first breath.

They feed on sea animals like squid. Their skin is smooth and slimy. Their forelimbs are used as flippers.

These dolphins are very sociable and they live in groups.

Dolphin

Group the dolphin into a vertebrate class

fish	amphibian	reptile	bird	mammal

Give reasons for your classification (catchwords).

Figure 2. Test material 2: animal card with text; second classification.

same animal. The participants of the sample group had the task of classifying the animals once again. This time they were asked to give reasons for their choice and they had as much time as they required. This classification card was supposed to reveal information on the theory-based classification.

This testing material was designed to mirror the two parts of the comparison process in order to find out whether pupils used the associative aspect or benefited also from the explanatory aspect.

Results

Pre-test

The initial focus was on spontaneous association. The associations were grouped into seven categories. Most of the associations were attributed to locomotion. Aspects attributed to habitat were often mentioned as well. These results coincide with earlier investigations (Kattmann and Schmitt, 1996). Those studies used other methods. Kattmann for instance let students classify vertebrates against their own criteria and let them give names to the groups. However, all investigations underline the dominance of locomotion and habitat for children, aspects that do not help in the classification of vertebrates.

Table 1. Categories of associations and percentages; pre-test n=76

Association fields	Stork (%)	Penguin (%)	Dolphin (%)
surface	3.9	10.4	18.2
properties	23.4	34.2	29.9
locomotion	42.9	28.9	39.0
habitat	26.0	18.4	7.8
nutrition	3.9	3.9	1.3
relationship to humans	1.0	1.3	1.3

Classification

Table 2 shows very little difference between the initial and second classifications. The data clearly show that classification based on the associative aspect of the comparison process dominates at this stage. Those pupils who had not by this stage understood the hierarchical classification system proposed two vertebrate classes for one species (5.3% for the first classification and 2.6% for the second).

Pupils' errors reveal their difficulties when classifying untypical animals. Less than half of the tested sample group classified penguins as birds. These findings suggest the unique use of the spontaneous associative aspect of the classification process.

Table 2. Initial classification of the penguin (picture-card) and second classification (information-card); Pre-test; n=76

Categories	Initial classification %	Second classification %
two animal classes	5.3	2.6
fish	10.7	11.7
amphibian	1.3	2.6
reptile	2.7	1.3
bird	44.0	45.5
mammal	36.0	36.4

The **reasons** show the criteria pupils used for classifying vertebrates. This paper proposes that the reasons for classification reveal the underlying understanding of vertebrate concepts. For the evaluation, the reasons were grouped into eight categories: four of them based on perceptual similarity and three consisted of a correct biological argumentation. Nonsense answers, no answers and circular arguments such as *'because I know it'* were included in an eighth category – 'no reasons'. The four everyday reasons are related to locomotion, habitat, nutrition, and perceptual similarity. The taxonomic reasons are divided into a superordinated reason (*they have lungs*), an argumentation with one correct reason and one with two or more correct reasons.

Table 3 shows that the largest part of the sample group was not able to give reasons (25%). The high level of false or no argumentation underlines the fact that classification at this time is not a solid tool with which to construct concepts. The next largest section of the sample group referred its answer to locomotion, followed by nutrition, habitat, and perceptual similarity. The use of taxonomically valuable arguments played a subordinate role.

Table 3. Reasons for the classification of the penguin, pre-test, n= 76, everyday arguments and biological arguments

Reasons	Sample Group (%)
Everyday reasoning	
no reasons	25.0
Locomotion	22.0
Nutrition	9.0
Habitat	9.0
Similarity	6.5
Biologically correct reasoning	
Super-ordinated reason	10.5
Single reason, class-related	9.0
2 or more reasons	9.0

Locomotion takes first place in spontaneous associations as well as in criteria for classification. These reasons correspond closely to spontaneous associations. The findings of this study lead to the conclusion that only the associative aspect of the classification process is enabled. The difficulties in classifying untypical organisms are obvious. The high amount of false or no arguments suggests that classification at this stage of development is only similarity-oriented and unsystematic. The errors in classifying the dolphin and the penguin were equally high.

These locomotion- and habitat-related reasons reveal analogy-related thinking in regard to vertebrate conceptions. From this point of view, a whale is conceptualised as a fish because it moves like a fish and looks like a fish and inhabits the same living space. Associations and reasons that are related to the adaptation of organisms play an important role in everyday thinking and sustain misconceptions of vertebrates.

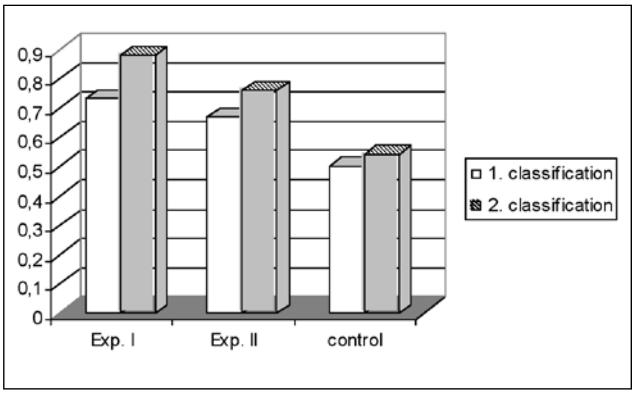


Figure 4. Initial classification (using the picture, as Figure 2) and second classification of the dolphin (information card, Figure 3). White column – first classification; shaded column – second classification; post-test

Post-test

In the post-test, pupils in groups I and II were seen to have performed better from the initial to the second classifications. This leads to the conclusion that they can now employ the explanatory aspect of classification when necessary. Those who corrected their own classifications found enough information in the text. The reasons given were based on theoretical knowledge conveyed via the explanatory aspect.

This ability was highest in group I (which received classification training + knowledge of natural history). The mean scores in Figure 4 show this improvement from the first to the second classification, with a slightly lower change in group II.

The classification abilities of the control group were considerably behind the other two even in the initial classification. The second classification did not substantially differ from the first. The control participants showed no improvement as far as classifying vertebrates was concerned. These pupils remained in everyday grouping habits. In the second classification exercise, group I and the control group differed significantly (mean score: 0.9 to 0.55). So, the first hypothesis can be viewed as accepted.

The **reasons for classification**, too, indicate the improvement of competence. They demonstrate that the experimental groups acquired more skills in taxonomic classification. Table 4 illustrates that the control group still argued with everyday reasons. Locomotion-orientated answers (25%) were in first place, habitat arguments (20%) in second while taxonomic reasons did not increase. Their understanding of classification and thus their conceptualising of vertebrates did not change. Their classification process relied on similarity-based comparisons.

While a quarter of the control group based its classification on locomotion – an indicator for similarity-based classification – this reason disappeared from group I. The class receiving training and history learning was able to shift from everyday criteria to taxonomically-relevant criteria. These criteria consist of homologies such as skin, skeleton, reproduction system, lungs, and circulation.

The control group, however, could not use both parts of the classification process. This is the reason why they did not build appropriate biological concepts. Their difficulties affect the correct classification as well. Only 50% of the control sample group classified the dolphin as a mammal while 88.5% of group I classified it correctly.

The analysis of the data suggests a shift from similarity-based classification to the use of the explanatory aspect: this means advanced classification abilities and the formation of correct concepts as well.

Does teaching the history of nature have an effect on the understanding of vertebrate concepts? A closer look at group II (classification training without natural history knowledge) shows that 76% of this sample group classified the dolphin correctly in the class of mammals. The sum of everyday reasons are higher than in group I. Some 14% argued for habitat and 4.8% still relied on similarity. The locomotion argument disappeared as well. The improvement was almost as high as the progression of group I. The difference between the groups may be explained by a more theory-orientated classification in group I. It can be deduced from this observation

Table 4. Reasons for the classification of the dolphin, post-test, control group, n=24; experimental group I, n=26; experimental group II, n=26

Reasons	Control group (%)	Group II (%)	Group I (%)
	Everyday reasoning		
no reasons	8.3	9.2	15.4
locomotion	25.0	0.0	0.0
nutrition	0.0	0.0	0.0
habitat	20.8	14.3	0.0
similarity	0.0	4.8	3.8
	Biologically correct reasoning		
Super-ordinated reason	8.3	9.5	15.4
Single reason, class related	0.0	42.9	50.0
2 or more reasons	12.5	19.0	15.4

that the history supports the selection of features. No-one in group I returned to a similarity-based orientation - neither locomotion nor habitat. The results were the same for all three animal cards.

Group I showed a consistent quality of classification since these pupils argued with more than 80% biologically-correct reasoning. These data suggest that the combination of classification training and evolutionary theory was successful. Sticking to the similarity-based classification of the control group means sticking to everyday classification patterns. This leads to a lack of biologically-based vertebrate concepts.

T-tests (paired samples between pre- and post-test) revealed significant differences between the three groups (two-sided, on 0.01 level for mean scores). Another t-test proved that only group I showed a significant shift from the pre- to the post-test in using taxonomic criteria (two-sided, on 0.05 level). This result underlines that a shift from similarity- to theory-based classification is due to greater learning activity. It supports the result that this method offers a way to improve the individual's construction of vertebrate concepts. These findings are compatible with the second hypothesis in that the history of nature as an explicit subject matter supports the explanatory aspect of the classification process.

Follow up-test

Six months later, the same pupils were tested once more. The test procedure was identical with the pre- and the post-test, except that they were shown animal cards with other species. The following table shows the results referring to the stingray.

The experimental groups continued to base their reasoning on taxonomic criteria. These pupils have managed to separate themselves from purely similarity-based classification. Group II, for example, used up to 85% biological arguments in their classifications. They obviously inserted the new view of classification into their previous concepts and built up reliable vertebrate class concepts. This may underline the proposition of this paper that the experimental groups really changed their conceptual understanding of vertebrates rather than just making a contextual switch. A high percentage of the control group, instead, found no reasons for their classifications (35%). And another 35% fell back into the use of everyday arguments. Their classification process was significantly different from those of the experimental groups. The process of classification in the control group did not shift from the everyday to a more theory-based classification.

Table 6, showing the correct classification of dolphin and orca, underlines the findings about the long term learning. While almost the entire experimental groups were able to classify an untypical vertebrate, only 65% of the control group classified it correctly. Both experimental groups had significantly enhanced their classification ability (t-test, paired samples, significant at 0.05 level).

Table 6. Correct classification of the dolphin and orca, pre-, post- and follow up-test; all three groups

	Pre-test	Post-test	Follow up-test
sample	dolphin	dolphin	orca
control	32.0	54.2	65.0
Group II	57.7	76.2	100.0
Group I	61.6	88.5	95.7

Conclusions

From the methodological view, this study provides a test instrument to highlight the hybrid model of comparison for didactical use. The classification test comprising both picture-based and rule-based classification may give results about the working of the two aspects of the comparison process. The picture-based first classification takes little time using spontaneous matching of similarities. The second classification test is focused on the explanatory part of the comparison operation.

This study demonstrates that the use of comparison in the experimental sample was extended by the explanatory aspect. This development of classification skills may be seen as a change of process. For the classification of vertebrates, the change proved to be helpful and led towards scientifically-appropriate classification. Further research should focus on the relation between the two aspects of the comparison process.

From the didactical point of view, this study suggests a learning approach to the introduction of vertebrates that is based on pupils' activities in the comparative method and that integrates evolutionary aspects of vertebrates from the beginning. As a change in vertebrate concepts needs a change of method, the teaching and learning of classification skills promotes a shift in the direction of theory-based classification. In the case of vertebrates, this produces a shift from analogy-based criteria to homology-oriented criteria. By acquiring more competencies in classification, pupils are able to enlarge or reconstruct vertebrate concepts in a constructivist manner. This approach fulfils the mentioned postulates for conceptual change, the confrontation with misconceptions

Table 5. Reasons for a classification of the stingray, follow up-test, all three groups

Reasons	Control Group (%) (n=20)	Group II (%) (n=20)	Group I (%) (n=23)
	Everyday reasoning		
no reasons	35.0	0.0	0.0
locomotion	5.0	0.0	4.5
nutrition	5.0	0.0	4.4
habitat	15.0	15.0	17.4
similarity	10.0	0.0	0.0
	Biologically correct reasoning		
Super-ordinated argument	25.0	15.0	26.1
Single reason, class related	5.0	30.0	21.7
2 or more arguments	0.0	40.0	26.1

and the understanding of an alternative explanation.

Theoretical knowledge like the natural history of vertebrates and the change of species supports the conceptualisation of vertebrates. This was shown by the differences between the performance of experimental group I and II. Experimental group I was taught about natural history and achieved better results than group II. The explanatory aspect was filled with appropriate knowledge for a phylogenetic classification of vertebrates. So, these pupils had the opportunity to rely for their reconstruction of vertebrate concepts on adequate non-perceptual knowledge. The third condition for conceptual change is also considered in this teaching approach as pupils actively find a better explanation for atypical specimens than by using similarity-based judgment.

The longer-term test shows that the conceptual change was deeply anchored in the individuals' representation system. After six months, pupils from the experimental groups still retained a scientific view of vertebrate concepts. It is likely that self-constructed enlargements of animal concepts were integrated into the mental representation and stayed there. These pupils will not switch between competing concepts in different contexts. The follow-up results prove that this constructivist way of conceptualisation is not a contextual change, but can be seen as a conceptual change. Further research should trace the conceptual change with other instrumental methods and determine whether the results will last for years.

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