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Students' alternative conceptions of animal classification

Presently the knowledge of species and taxonomic categories is becoming more important for biology lessons again, as greater emphasis is laid on ecological studies and the understanding of biodiversity.

In the view of evolution, biodiversity is not restricted to species level, but extends beyond it. *Below* the species level, the diversity of populations and individuals are to be acknowledged. Due to social, psychological and educational reasons this issue is especially important in the human species (cf. Hirschfeld, 1995; Kattmann 2011).

Above the species level, the biodiversity of taxonomical groups and ecosystems are to be mentioned.

This study is concerned with the understanding how groups of animals belong together. In the view of evolution and phylogenetic systematics, taxonomic groups of animals ought to be a monophylum, i.e. their members are descendants of one common ancestor, and thus are joined by genealogy. But in the view of students, and most of biologically non-educated persons, animals are classified in quite another way. The significance of alternative, everyday conceptions for biology learning and biology education is the subject of the study presented here.

Educational background of the study

The efforts in biology education to gain a better understanding of biodiversity will fail if the conceptions of students in this field will go on being neglected. In a constructivist perspective, scientific conceptions cannot be simply transferred from the teacher to the students. Instead, the everyday conceptions of students must be understood and used as preconditions for the design of learning environments as proposed by the Model of Educational Reconstruction (Kattmann, 2007; cf. Duit, Gropengießer & Kattmann, 2005). Teaching should be therefore built up from the conceptions of the students in a larger degree than it is practised today. In accordance with this principle, a study was conducted to find out how students would classify animals, if they were allowed to develop and apply their own criteria and categories. Therefore the students were not confronted with biological taxa, nor were they asked to use taxonomic categories, as it had been done in most of the former studies (cf. Natadze, 1963; Ryman, 1974; Trowbridge & Mintzes, 1985; 1988; Mintzes & Trowbridge, 1987; Braund, 1991; 1998). Instead they had the opportunity to sort a set of animals in an order that made sense to them.

Research questions and methods

The study was conducted to answer the following questions:

- Which criteria of classifying animals are applied by the students themselves?
- Which opportunities are opened by the personal conceptions of the students for the meaningful learning of biological diversity?

The students' conceptions were investigated by a questionnaire, which contains three parts (see the appendix).

Grouping and naming (task 1)

A set of 25 names of animals is given. In a pilot study we asked students aged 9 to 10 to write down names of as many animals as they could. Thus it was confirmed that the names of the animals used in our study were familiar even to the students of lower grades. For this reason colloquial names of animals are used, also those which refer to a number of species, e. g. lizard. The task is to sort the animals into groups and to find an appropriate name for every group (s. fig. 1). The category "single" is provided so that the students should not feel obliged to fit every animal into a group. The questionnaire does not include pictures of the animals. Using just names, we made sure that the students could construct and use their mental models most freely (cf. Duit & Glynn, 1996) and that their attention was not attracted by accidental features of specimens, photos or drawings (see also the discussion below).

Odd one out (task 2 with 6 items, see the appendix)

Each item consists of a multiple-choice part and a free-answer part. In the multiple-choice part, out of a group of 5 animals one animal must be chosen, the one which – according to the conception of the student – does not belong to the group. The reason for the choice has to be given in the free-answer part. The groups are composed in such a way that the students can find a member which does not fit in the sense of biological taxonomy, and another one which fits, but differs from the other members either in locomotion, habitat or size.

Allocating (task 3 with 5 items, see the appendix)

Each item consists of a two-choice part and a free-answer part. The student has the choice to put one of two animals into a group of 3 or 4 animals. The reason for the choice has to be given in the free-answer part.

The study was conducted with 536 students of Lower Saxony and North-Rhine-Westfalia. In detail 93 students of grade 4 (9 to 10 years, primary school) 174 of grade 5 (10 to 11 years) and 269 students of grade 7/8 (13 to 16 years, Comprehensive School and Grammar School) participated in the survey. The investigation was carried out in co-operation with 12 teachers, who were familiar with the design and with the aims of the study through proceedings of teacher in-service.

Fig. 1. Grouping and naming: Example of the answers of a student (Grade 5) Questionaire task 1 (German original, English translation: see appendix)

Results

– Grouping and naming

In the following the terms "non-taxonomic" and "taxonomic" are used in the biological sense.

The main results are presented in figure 2 and table 1. Obviously *non-taxonomic categories* are predominant. The ratios of students using non-taxonomic criteria are given in figure 3. The orientation in classifying along habitat dominates in all grades. The category "aquatic animal" has the first rank in all grades. Nearly each student of grade 4 and 5 forms this group and so do even two-thirds of the students of grade 7/8 (table 1).

The second important role is played by the orientation on locomotion (especially flying and creeping).

Tab. 1. Grouping and naming: Results (task 1) Included are groups and names which reached a ratio of 10 % and more in one grade. Similar names were comprised (in brackets: percentage of students; N: number of students with evaluable answers). Correlations of ranks (seven first places): grades 4 and 5: r = .74 (p<.05); 5 and 7/8: r = .53 (n.s.); 4 and 7/8: r = .15 (n.s.)

Grade 4 (N = 83)		Grade 5 (N = 138)		Grade 7/8 (N = 262)	
1. aquatic animals	(86,7)	1. aquatic animals	(90,6)	1. aquatic animals	(66,0)
2. flying animals	(69,9)	2. flying animals	(45,0)	2. insects	(60,7)
3. four- or two-legged animals	(65,1)	3. insects	(43,5)	3. mammals	(51,5)
4. creeping animals	(48,2)	4. domestic animals	(43,5)	4. birds	(43,1)
5. insects	(27,7)	5. creeping animals	(42,0)	5. domestic animals	(34,4)
6. domestic animals	(16,9)	6. mammals	(23,2)	6. reptiles	(31,7)
7. terrestrial animals	(15,7)	7. four- or two-legged animals	(18,8)	7. flying animals	(30,2)
8. large or small animals	(14,5)	8. birds	(13,8)	8. creeping animals	(22,1)
9. fast or slow animals	(10,8)	9. large or small animals	(12,3)	9. amphibians	(18,3)
		10. exotic animals	(10,1)	10. vertebrates	(14,5)
				11. fishes	(13,4)
				12. molluscs	(11,5)
– birds	(4,8)	– terrestrial animals	(8,0)	– four- or two-legged animals	(5,0)
– mammals	(1,2)	– reptiles	(6,5)	– terrestrial animals	(4,2)
– reptiles	(1,2)				

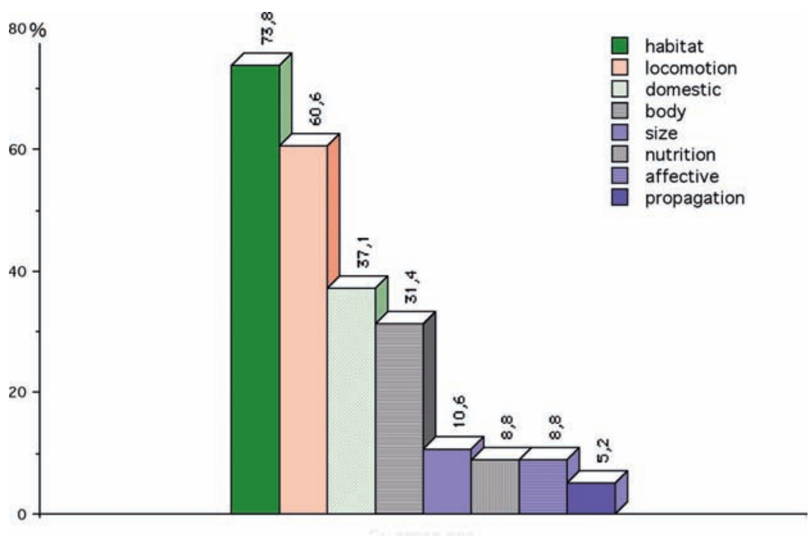

Fig. 2. Grouping and naming: Results over all grades (task 1)

In spite of this, morphological or anatomical characteristics play a minor role. Only the criterion "number of legs", by which the students formed groups of animals with four legs and with two legs, respectively, is worth mentioning for grade 4

(65%). The frequency of this criterion diminishes in the higher grades while taxonomic categories increase.

In all grades number and frequency of *taxonomic categories* are significantly lower than non-taxonomic, but they are higher in grade 7/8 than in grades 5 and 4. The forming of taxonomic groups seems to increase continuously, but the frequency is low even in grade 7/8: Only the group "insects" and the group "mammals" are formed by more than half of the students of this grade (table 1).

– Odd one out and allocating

Results of the two tasks are given in figures 3 and 4.

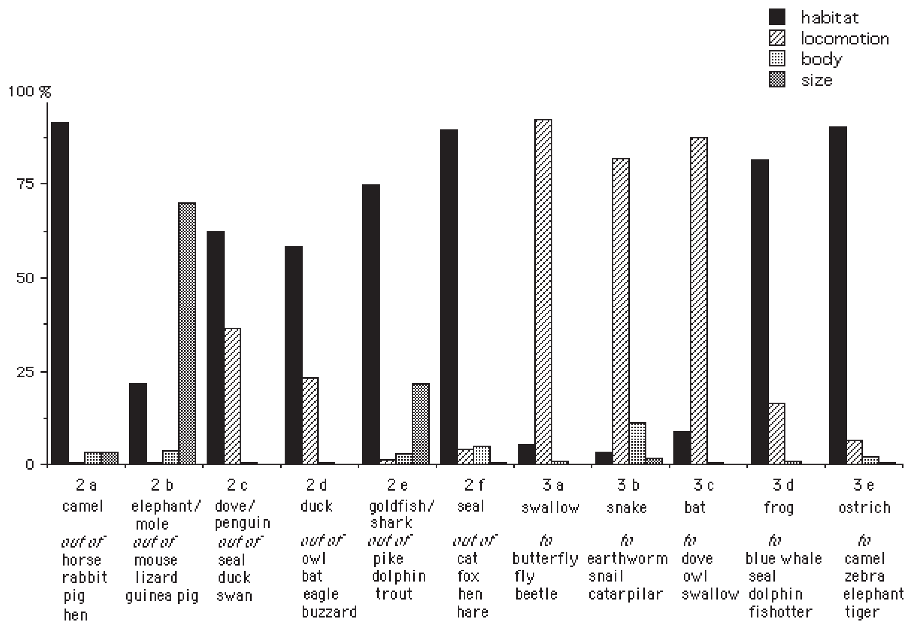

Fig. 3. Odd one out and allocating: Criteria of non-taxonomic choices (inconsistent reasons less than 1%; tasks 2 and 3, all grades)

The results are overall consistent.

– With a few exceptions, the ratio of the taxonomic choices is lower than that of non-taxonomic choices. If the results of both tasks are comprised, the ratios of non-taxonomic choices sum up to 97% in grade 4, 92% in grade 5 and still more than two-thirds in grade 7/8 (65%).
– The criteria of habitat and locomotion are the most frequent (see fig 3).
– Often the reason for the taxonomic choice is inconsistent with the choice (i.e. the taxonomic choice is explained with non-taxonomic reasons, see fig. 4). In contrast, the non-taxonomic choices are generally consistent. Only in 1% of these choices an inconsistent reason is given.

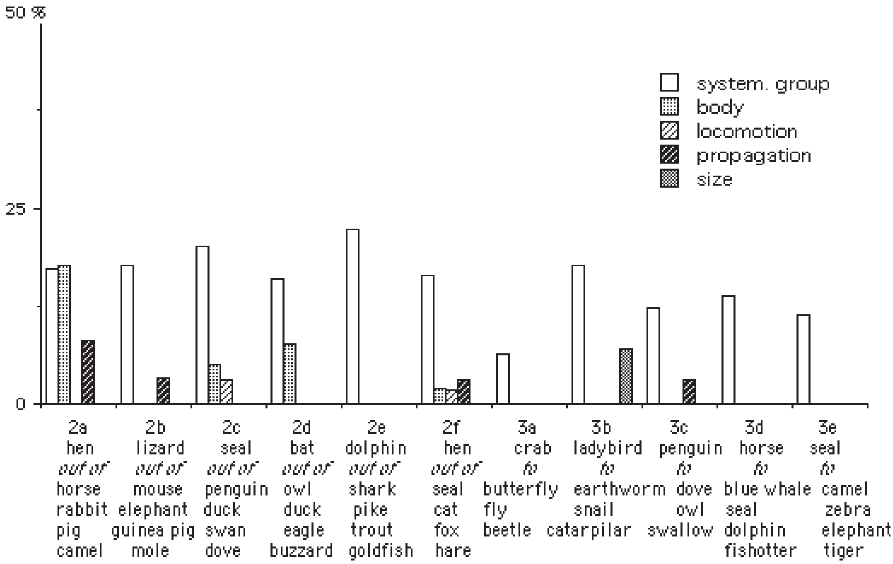

Fig. 4. Odd one out and allocating: Criteria of taxonomic choices (inconsistent reasons included; tasks 2 and 3, all grades)

Interpretation of the results

Consistency of criteria choosing and coexistence of different taxonomies

The questionnaire makes it possible to test whether an individual student consistently chooses taxonomic or non-taxonomic criteria over all the items. The results show that consistency is very different between taxonomic and non-taxonomic criteria (see table 2). The probability of consistency is the same for both categories of the criteria. If there were no bias in choosing the criteria, one should expect that a majority of students would be inconsistent in choosing criteria. That is not the case. Over all grades more students are consistent in choosing non-taxonomic criteria although the ratio decreases with higher grades. In grades 4 and 5 no student is consistent in choosing taxonomic criteria and only a minority of about 4% is consistent in grade 7/8.

The predominance of non-taxonomic criteria (mainly habitat and locomotion) is apparent in grades 4 and 5. Accordingly, the students use several non-taxonomic criteria creating their personal taxonomies. The criteria biologists apply in establishing a scientific taxonomy play an insignificant role, or none at all, for the students. The problems of students, which were found in previous studies of several researchers, may therefore be deeper and more comprehensive than it is supposed by many biology educators. In grade 7/8 taxonomic and non-taxonomic criteria are used side by side by most of the students. The greater ratio of taxonomic choices in grade 7/8 shows that taxonomic classification is learnt during biology lessons and partly applied by the students. The criteria of biological taxonomy thus join those of personal taxonomies but do not replace them.

Tab. 2. Consistency of students' choices by taxonomic and non-taxonomic criteria. The results for grades 4, 5 and 7/8 are placed in three following rows

Consistency of Choices	Grouping (task 1) %	Odd one out (task 2) %	Allocating (task 3) %	*All tasks %*
Consistently non-taxonomic	68,7 47,1 21,8	86,0 66,7 25,6	89,8 77,7 41,5	50,6 29,7 8,2
Consistently taxonomic	0 2,2 14,5	0 1,4 13,9	0 0 8,1	0 0 3,7
inconsistent	31,3 50,7 63,7	14,0 31,9 60,5	10,2 22,3 50,4	49,4 70,3 88,1
valuable/non evaluable cases (students who fail to answer at least one item)	483 /53	454/82	461/75	440/99

Evidence for an implicit theory of kinship

The differences in classification between the grades cannot be explained by growing skills of classification. The ability of classifying hierarchically is present already in students of grade 4 (age 9-10; cf. Inhelder & Piaget, 1973; Markman, 1985). The results of our study do not show an increase in the differentiation of categories. On the contrary, the number of categories decreases from a mean of 3.3 in grade 4 to 2.7 in grade 8. Furthermore, the consistency in using categories diminishes dramatically from 50.6 % in grade 4 to 19.9% in grade 7/8. Thus only a change of the categories used is evident. The findings cannot be explained sufficiently, neither by classical theories of concept forming and logical classification (cf. e.g. Bruner, Goodnow & Austin, 1956; Clark, 1973) nor by prototypical approaches (cf. e.g. Rosch et al., 1976; Mervis & Rosch, 1981). In the personal taxonomies of the students, the visible features of the body play quite a marginal role. If birds and flying insects are put together into one group, one can hardly speak of a typological approach. Flying is the only visible phenomenon which is common to all the members of the group and which is therefore decisive. Even the habitus cannot be responsible for forming the group, because a similarity of the habitus of a swallow and that of a beetle or a butterfly is not detectable at all. The same is true for classifying the frog with the aquatic mammals only because it spends its life in the water.

Our study seems to indicate that the personal taxonomies of the students are not derived by computing features but constructed systematically on the basis of a comprehensive world-view. In this world-view the environment may be divided into elementary domains which all together represent a wholeness of reality. The classification is supposed to be oriented towards a scheme providing them with explanatory principles for the elementary order of living things. This scheme, which the students need not be aware of, can be called an implicit theory of animal kinship.

The reasons, which the students give in tasks 2 and 3, indicate that habitat and locomotion are seen only as one and the same group of criteria so that they can substitute one another. Accordingly, the criteria used in task 1 can be associated to four large areas of life, which are called "elements":

– Water (aquatic animals, swimming)
– Air (air living animals, flying animals)
– Ground (creepers, crawling animals)
– Land (land living animals, running animals, fourlegs, game and domestic animals).

The groups of the last "element" seem to be heterogeneous, but this configuration is justified because the members of the groups formed are usually the same.

In grade 4 the first four most frequent categories do reflect the four "elements" accurately: Aquatics, Flyers, Creepers and Terrestrials.

The results of the study indicate that students may have an implicit theory of animal kinship, which is oriented towards the large areas of living and which can be characterised as elementary ordering. This theory is domain specific. It applies only to a medium level classification, which in ethnozoology is called "life form", i.e. the level of larger groups, not of species and genus. The latter are formed by typological or prototypological categories instead, whereas the highest levels (e. g. plant and animal) are formed through abstraction.

Findings of former studies, which refer to a medium level of classification (e.g. the classifying into classes or the distinction of vertebrates and invertebrates) should therefore be revisited in the light of the supposed implicit theory of the students (for more details cf. Kattmann, 2001; Kattmann & Schmitt, 1996).

Discussion

The results of Tunnicliffe & Reiss (1999) seem to contradict our results. In naming and grouping six animals presented as conserved specimens, the orientation of the students was clearly dominated by the criteria of "anatomy". The different results are mainly due to the number and set of animals presented. The small number of just six animals in the study of Tunnicliffe and Reiss causes the students to compute the features as it is usually done on species level. When a larger number of animals, including those of several habitats, are taken into account, as in the studies reported, the diversity of animals requires a more general orientation, which encourages the students to construct or use their own mental models.

One could assume that the perception of specimens may lead the students to be predominantly guided by sensation and not by imagination. But this assumption is disproved by a teaching experiment with students of one class of grade 7 of a Grammar School (N=22, 13–14 years old). In this follow-up study, the students were asked to group a set of 19 vertebrates, which were presented as preserved specimens (Sonnefeld & Kattmann, 2002). The results totally confirm the outcome of the study presented here: More than 80 % (18 of 22) of the students used the criterion of habitat, 45 % (10 of 22) – of locomotion, and only 9 % (2 of 22) – the criterion of anatomy. After group discussions, five of six groups used the criterion of habitat, and one group was not able to decide between the criteria of nutrition, habitat and taxonomy. After a free discussion in the class all the students agreed that habitat is the most valid criterion for the classification of the 19 animals presented.

The results of the study presented here were also confirmed by a Greek study with primary teachers, in which the same questionnaire (after Kattmann, 2000) was used (Papadopoulou & Athanassiou, 2002). Further evidence is given by the comprehensive study of Hammann (2002) on the method of comparison in biology teaching.

Educational implications

Teaching which neglects the conceptions of the students will have no success in trying to overcome the difficulties students have in understanding and applying biological classification. Those difficulties may not be caused by deficient generalisation or logical thinking but can be due to the conflict between the biological criteria and elementary ones. This can also explain why whales and dolphins are still classified as fish, while the same students were able to point out that their features are those of mammals (cf. Natadze, 1963).

To overcome the learning difficulties, imprinting of group features or the exercise on the principles of generalisation and logic of classification are proposed by several authors (cf. Trowbridge & Mintzes, 1985, p. 313 f.; Braund, 1991, p. 109; Braund, 1998). According to the findings of the study presented here, these approaches are of limited value. They relate to an instructivistic rather than to a constructivist conception of teaching and learning.

If implicit theories and personal taxonomies are the students' reasons for animals classification, different views and perspectives should be reflected in order to appreciate their function in different contexts. Thereby students must have the chance to develop and apply their own conceptions adequately to the problem.

On this basis, an educationally reconstructed teaching unit for grade 5 was developed, which is concerned with the classifying of the classes of vertebrates (cf. Baumann, Harwardt, Schoppe & Kattmann, 1996, s. table 2). The basic idea of constructing this unit is to use the fundamental orientation of the students on habitat for the biological classification. Consequently, the classification in the biological sense is closely linked to an ecological and evolutionary approach. Thus, the Educational Reconstruction does not only make it possible to consider students' conceptions but opens up a new view to scientific theories as well: in considering that the phylogenetic groups of animals evolved in interdependence with the habitat, the phylogenetic taxonomy can be seen and worked out along this aspect. Following the evolutionary path of vertebrates from water to land, the large groups of vertebrates are formed phylogenetically. Students generally are highly motivated to get information about whales, bats, penguins and platypus or the care of the brood in crocodiles. Thus the evolutionary approach is not only scientifically more adequate than the logical classification along features, but at the same time meets the conceptions and interests of the students. In this way the unit is paradigmatic for the "natural history concept" of biology teaching, in which evolutionary theory serves as the basic explanatory principle (cf. Kattmann, 1995).

Tab. 3. Outline of a teaching unit for classifying vertebrates

From Water to Land - and Back again
Natural History and the Classification of Vertebrates

(1) Habitats: Mirrors of evolutionary order
Phylogenetic groups can be classified according to their original ecological zones.
Introduction into evolutionary thinking: Vertebrates first evolved in the water and settled on land from there. This history corresponds with the large groups of vertebrates:
– Fishes (water),
– Amphibians (water and land),
– Amniotes (terrestrial vertebrates: land and air).
Thus a provisional order of vertebrates can be achieved through the orientation towards habitats.

(2) Valid signs: Tracks of history
Aquatic vertebrates are the forerunners of terrestrial ones. But terrestrial animals can return to water.
History matters:
A comparison of the lifecycle of a salamander and a lizard reveals the phylogenetic kinship: The characteristic trait of the amniotes is to lay eggs on land.
Thus with students working like detectives aquatic living amniota (e. g. crocodiles and some tortoises) are recognised as such. The egg-laying platypus helps to relate the mammals to the other amniotes.

(3) Traits of help: Feathers and hairs
Kinship is not caused by similarity but by communal history.
Traits and features of the body (e. g. feathers or hairs) are means only in helping to classify validly.
Thus erroneous associations are corrected: Bats, whales and penguins join their phylogenetic group (mammals and birds respectively).

(4) Radiation into several habitats
Secondarily vertebrates of different groups settled into various habitats followed by a great diversification of life forms. Mammals are living e. g like birds (bats), fishes (whales) and amphibians (seal). The reptiles of Cretaceous times can serve as another example.
Thus the diversification within the classes of vertebrates is recognised, especially in mammals, birds and reptiles.

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Appendix

Which of the animals belong together?

On the following sheets there is a number of tasks for you, but this is not a test. Your answers will help us to improve biology teaching.
There is no right or wrong. We like to get your personal choices and reasons.

1. In this task you will find a number names of animals you certainly know. You will note that some of the animals belong together

Underline all names of animals which belong together with <u>one</u> colour.
Afterwards give an adequate name to each group you formed!
You can also invent adequate names if you like.

dog cat butterfly earthworm

wasp hen snail spider

snake fox fly seal beetle

hamster duck crab lion

herring swallow frog mouse

elephant jellyfish lizard starfish

Find a name for each group:

Red: ....

Green: ....

Blue: ....

Yellow: ....

Black: ....

....

If you don't want to include an animal in any of the groups, write the name of this animal into row of "singles"!

"Singles": ....

2. In the following tasks five names of animals are given.
Only four of them belong together.

a) Which of the animals does not belong to the group? Mark its name:

❑ horse
❑ rabbit
❑ pig
❑ hen
❑ camel

Please give the reason why this animal does not fit into the group:

....

b) Which of the animals does not belong to the group? Mark its name:

❑ mouse
❑ lizard
❑ mole
❑ guinea pig
❑ elephant

Please give the reason why this animal does not fit into the group:

....

c) Which of the animals does not belong to the group? Mark its name:

❑ seal
❑ duck
❑ penguin
❑ swan
❑ dove

Please give the reason why this animal does not fit into the group:

....

d) Which of the animals does not belong to the group? Mark its name:

❑ owl
❑ duck

❑ bat
❑ eagle
❑ buzzard

Please give the reason why this animal does not fit into the group:

....

e) Which of the animals does not belong to the group? Mark its name:

❑ shark
❑ pike
❑ dolphin
❑ trout
❑ goldfish

Please give the reason why this animal does not fit into the group:

....

f) Which of the animals does not belong to the group? Mark its name:

❑ seal
❑ cat
❑ fox
❑ hen
❑ hare

Please give the reason why this animal does not fit into the group:

....

3. In the following tasks you will find groups of animals which belong together:

a) butterfly
fly
beetle
dragonfly

Which of the following animals fits into the group? Mark its name:

❑ crab
❑ swallow

Please give the reason, why according to your opinion the animal chosen fits into the group of the other four animals:

....

b) earthworm
snail
caterpillar

Which of the following animals fits into the group? Mark its name:

❑ snake
❑ ladybird

Please give the reason, why according to your opinion the animal chosen fits into the group of the other three animals:

....

c) dove
owl
swallow
eagle

Which of the following animals fits into the group? Mark its name:

❑ penguin
❑ bat

Please give the reason, why according to your opinion the animal chosen fits into the group of the other four animals:

....

d) blue whale
seal
dolphin
otter

Which of the following animals fits into the group? Mark its name:

❑ frog
❑ horse

Please give the reason, why according to your opinion the animal chosen fits into the group of the other four animals:

....

e) camel
zebra
elephant
tiger

Which of the following animals fits into the group? Mark its name:

❑ seal
❑ ostrich

Please give the reason, why according to your opinion the animal chosen fits into the group of the other four animals:

....

Students' alternative conceptions of animal classification

Abstract

Students' conceptions of animal classification are the subject of several investigations. In previous research the criteria of classification used by the students were generally neglected. In a constructivistic view of learning and teaching these investigations must be judged as fallacious The study presented here shows that students prefer to classify creatures along the criteria of habitat and locomotion. They maintain using these criteria even after learning the categories of biological taxonomy. The results point to the assumption that students have an implicit theory of natural kinship of animals.
The „personal taxonomies" of the students investigated are expected to be important means for or hints of learning biological systematic and therefore should be seriously taken into account in biology teaching, especially with regard to biological taxonomy, biodiversity and evolution.
In accord with the results of the research, the outline of a teaching unit on the evolutionary approach to the classification of vertebrates is presented.

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