The ‘system of pasta’ – an introduction to dichotomous keys

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ABSTRACT Familiarity with species and species identification seem to be a prerequisite for understanding biodiversity and many syllabuses and practitioners emphasise the use of dichotomous keys. Previous studies revealed that pupils using illustrated identification books often coped better with identification tasks than pupils using dichotomous keys. One reason might be that pupils were confronted with two cognitive tasks simultaneously: how to use the key, and identifying the species. This article introduces a dichotomous key based on the identification of ‘species’ of pasta, familiar to pupils from their everyday life. Their task is to learn how the key itself works rather than focusing on identification. In a subsequent lesson, pupils focus on amphibian identification. Pupils who has used the pasta system performed significantly better than a control group, suggesting that training on dichotomous keys should be fostered by using familiar items.

To gain insight into biodiversity and to understand ecology and ecological interactions, at least some basic knowledge about species, their natural history and life history, is essential (Lindemann-Mathies, 2002, 2005). Animals are highly esteemed by children, especially at the school level, and species can be used in a ‘bottom-up’ approach to ecology, starting with single species and then widening the scope to cover interactions, trophic webs and predation. Therefore, some training in species identification is a useful tool for biology education. Some basics should be considered when pupils are taught species identification. The number of species used should be limited (Randler and Bogner, 2006). Also, studies have revealed that pupils often learn better if they have the opportunity to explore new fields of knowledge autonomously in a pupil-centred environment, to feel competent and learn in a social context (self-determination theory).

In such a learner-centred environment familiar materials can be used for teaching pupils the use of dichotomous identification keys (e.g. Randler and Zehender, 2006). Many syllabuses and curricula explicitly suggest using dichotomous keys as a scientific tool. Dichotomous keys are based on making a decision between two alternatives, followed by another pair of alternatives unless the final species name (or other taxonomic level, such as genus or family) is reached. If coloured printed keys or books are used for identification, pupils often focus on the pictures alone. The benefit of using dichotomous keys is that pupils have to take a closer and more detailed look at the objects or models. Further, in comparison with books, such keys are scientifically more precise and foster the understanding of scientific terms. Despite those clear benefits of dichotomous identification keys, Randler and Knape (2007) found pupils who used illustrated identification material (a selection of pictures for identification) scored significantly higher in learning and retention. One reason why dichotomous keys yield worse results may be found in the ‘cognitive load theory’ (Sweller, van Merrienboer and Paas, 1998; see Box 1). <BOX 1>

The aim of this present study was to enhance learning and retention when pupils were working together in small groups on an identification-skill training exercise using a dichotomous key for identifying amphibians. We developed educational material to introduce the structure and functioning of a dichotomous key, using familiar objects (pasta ‘species’) that do not provide difficulties of identification (hence less intrinsic load, perhaps none). This, in turn, enables pupils to focus on the instructional material (extraneous cognitive
load; see Box 1). In the subsequent lessons, pupils were therefore already familiar with the system and structure of a dichotomous key, and we hoped they would benefit more from the lesson on amphibian identification because the extraneous cognitive load had been reduced.

**BOX 1 Theory of cognitive load (Sweller et al., 1998)**

According to this theory, brain capacity can be divided into a short-term working memory and an effectively unlimited long-term memory. The theory assumes a limited-capacity working memory that includes partially independent subcomponents to deal with auditory/verbal material and visual more-dimensional information (Sweller et al., 1998). The unlimited long-term memory holds schemas that vary in their degree of automation. Three aspects of cognitive load are mentioned:

- The **intrinsic** cognitive load represents the learning content itself, in this specific case the different amphibian species. There is a moderate element interactivity, that is, if you have learnt one of the species this helps you in learning the other one as amphibian species can be grouped taxonomically. Hence intrinsic load could be considered moderate.

- The instructional design poses an **extraneous** cognitive load in the working memory, that is, materials are presented differently. In this case, the dichotomous key poses an extraneous cognitive load since following such a key is difficult itself and this cognitive load reduces working memory capacity that should be available for learning the species’ names. Such an extraneous cognitive load is caused entirely by the format of instruction.

- **Germane** cognitive load is used for schema construction, which is essential for long-term memory. This is necessary to construct a ‘picture’ or schema, for example of different species of frog, toad or newt. By reducing the extraneous cognitive load more brain capacity is available for a ‘germane’ load which aids schema representation (and construction in the long-term memory).

**Details of methodology**

**Training unit ‘System of pasta’**

The training unit ‘System of pasta’ was adapted from an idea presented in Probst, 2002. In this, pupils were encouraged to construct a ‘system of pasta’ from a constructivist viewpoint. We developed the idea further, establishing a dichotomous identification key for different ‘species’ of pasta, such as lasagne, tortellini, spaghetti, macaroni, and others (see Figure 1). The benefit of the pasta system is that pupils are familiar with it and can therefore focus on the use of the key. The different species of pasta were also presented in the classroom to make use of real objects.

**Selection of amphibian species**

We chose eight autochthonous amphibian species that live and reproduce in Saxonia (Sachsen in German), one of Germany’s sixteen federal states. The species were: fire salamander (*Salamandra salamandra*), common newt (*Triturus vulgaris*), great crested newt (*Triturus cristatus*), natterjack toad (*Bufo calamita*), common toad (*Bufo bufo*), tree frog (*Hyla arborea*), edible frog (*Rana kl. esculenta*) and common frog (*Rana temporaria*). Criteria for selection were abundance, population size and distribution estimated from grid maps. All species were exhibited in the classroom both as naturalistic models and as photographs (A 4 size, coloured). These models closely resembled live amphibians. They were obtained from a scientific producer (SOMSO; Schlüter Biologie, Winnenden, Germany). Pupils primarily worked with the colour prints.

**Educational programme and test instrument**

Pupils worked together in groups of four, and every group received a set of amphibian pictures. Every pupil further received a coloured sheet where the species were depicted in a smaller size and where identification traits could be written. After pupils had finished their work, results were discussed and corrected in classroom discussion. We used a pre-test, an immediate post-test and a retention test (delayed four weeks). Pupils received a coloured sheet where they had to label the respective species as precisely as possible. As pupils often have less prior knowledge we chose four species for the pre-test. During the immediate post-test all eight species were presented and
the pupils were asked to label them. Two further questions were asked during the post-test:

- the difference between frogs and toads (skin);
- the difference between newts and salamanders (round versus flat tail).

The retention test, again, used all eight amphibian species.

The test sheet contained coloured photographs of live amphibians. To minimise effects of repeated testing, we altered the order of species presentation between the tests, and used different photographs for each of the three tests. This avoids the possibility that pupils may memorise species, for example, by their gaze direction (e.g. if the common newt is facing right and the fire salamander facing left, then retention effects may arise because pupils have learned the direction of gazing rather than the species’ characteristics). We scored every correct identification at the species level with 1.0 and every correct identification at the genus level with 0.5. Others received the value 0. This was added to a total score for each participant. The logic behind this scoring is that an increase in knowledge is reflected in a correct identification at the genus level. For example, the common newt may be unknown to someone but after an educational intervention it is identified on the genus level (e.g. as a newt). This is considered as an improvement or refinement of a concept (see discussion in Randler and Bogner, 2006).

**Emotional variables and pupils’ responses**

Emotional variables were measured from the inventory proposed by Gläser-Zikuda et al. (2005). These constructs are based on four different dimensions: interest, well-being, boredom and difficulty of the task, based on a five-point Likert-scale. We used one item per emotional construct.

A further question was ‘*Would you make use of such a key in your spare time?*’ and the treatment group (which received the pasta training) was asked ‘*Did you find the training helpful?*’

**Pupil sample and randomisation**

104 pupils (42 boys, 62 girls), all 5th graders (age 10–12 year-olds), from four different classes participated in our study and filled out all three tests. The treatments were randomly assigned to two classes each (quasi-experimental approach). Two classes received the pasta training unit in advance ($N = 42$) and two others did not ($N = 62$). (It is a coincidence that the number receiving the advance training was the same as the number of boys; it does not mean that all the boys received the training whilst the girls did not.) Three classes (77 students) came from the Gymnasium, a name given in Saxonia to classes selected by ability.
One class (27 students) was from the middle school (lower ability).

Statistics
For comparison of the means we used t-tests and to investigate differences in a more complex manner and controlling for covariance and interactions a general linear model was applied (GLM). All tests were carried out two-tailed. We used SPSS version 13.0. Means ± standard errors (s.e.) are given.

Results
Species identification
Pupils from both groups differed significantly in their prior knowledge (Table 1; Figure 2). Differences between both groups remained highly significant immediately after the educational intervention, and again after four weeks.

As both groups differed in their prior knowledge (Figure 2), we applied a multivariate general linear model (GLM) with pre-test as covariate, and gender, school stratification (medium versus high stratification) and intervention (pasta training yes/no) as factors. After accounting for the covariate pre-test, the influence of the pasta training remained significant (see Table 2). Further, there were no significant effects of gender or of school stratification, nor any significant interaction between the variables. These results suggest that both boys and girls benefited equally from the programme, and that both stratification levels scored similarly after accounting for prior knowledge. Figure 3 depicts the results after accounting for differences in prior knowledge (covariate-adjusted means). Although the effect is smaller, differences remain significant. The amount of explained variance (as measured by partial eta$^2$) indicates a moderate effect size, which emphasises an educationally relevant effect. Partial eta$^2$ was 0.06 in the post-test and 0.11 in retention, suggesting a higher impact of the pasta training on retention.

Emotional variables
There were no significant differences between the groups in emotional variables ($p$ always >0.05). However, when pooling post-test results of both groups we found rather high interest (4.33 ± 0.08 on the Likert scale), high well-being (4.15 ± 0.10) and low boredom (1.47 ± 0.09). Pupils assessed their task as less difficult (1.97 ± 0.11) but would not necessarily make use of a dichotomous key in their spare time (3.29 ± 0.13). Pupils who received the pasta training unit found the key helpful (3.83 ± 0.20). In detail, 18 pupils found it very helpful (42.9%) and 11 helpful (26.2%).

Discussion
These results suggest that an additional training on ‘pasta species’ prior to an educational programme of species identification significantly increases knowledge immediately thereafter and after a delay of four weeks. We therefore suggest and emphasise the use of dichotomous identification keys but only after proper preparation of the pupils (with training such as that suggested here). Further, we believe that the pasta training

![Figure 2](image)

**Figure 2** Differences between <control and treatment?> groups in the three different tests; the treatment group received the additional pasta training.

| Table 1 Comparison of the test scores (means and standard errors) |
|-----------------|-----------------|-----------------|
|                 | Pre-test         | Post-test       | Retention      |
| Pasta training group | 2.26 ± 0.11     | 8.68 ± 0.17     | 6.71 ± 0.15    |
| Control group     | 1.64 ± 0.11     | 7.38 ± 0.22     | 5.23 ± 0.20    |
| t-test            | $t = 3.78; df = 104$; | $t = 4.19; df = 104$; | $t = 5.16; df = 102$;  |
| p                 | <0.001           | <0.001          | <0.001         |
This study provides an example of how results from strict psychological studies (see Box 1) – which are often obtained under laboratory conditions – can be transferred meaningfully into everyday teaching and learning. Further, we believe that this study could be generalised within the field of science education.

There were no gender differences and we assume that both boys and girls benefited equally from the educational programme.

**Educational implications**

The educational implications seem clear. After some discussion about the usefulness of dichotomous keys (e.g. Randler and Knape, 2007), we have emphasised their usefulness. Pupils using such keys learn a scientific method and foster their methodological skills. Use of the pasta system is one example of how to familiarise pupils with the method per se before starting to apply the key to real situations.

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**References**


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**Table 2 Results of a general linear model using pre-test as covariate, gender and treatment as factors.**

Post-test and retention test were used as dependent variables.

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Figure 3 Differences between <control and treatment?> groups after accounting for differences in the pre-test; covariate adjusted means derived from a general linear model

Indeed reduces the extraneous cognitive load and enhances brain capacity so that pupils are able to focus on the educational content – in this case the amphibian identification task.

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