

Teachers' Aims in Anatomical and Morphological Comparisons: an empirical study

Marcus Hammann

SUMMARY

Comparisons have two main functions in the teaching of biology: On the one hand, they can be used as a source of information in order to develop the students' knowledge and comprehension of the subject matter. As an alternative to experimentation, on the other hand, the comparative method is a major mode of scientific inquiry and can be used to familiarise students with basic ways of thinking and operating in science. Intending to clarify the dual role of comparisons, this study investigates which aims teachers consider important when they engage their students in anatomical and morphological comparisons in grades 5-13. The teachers' responses (n=351) show that the contours of comparisons as a method of scientific inquiry become sharper the more advanced the learning level of the students is. In particular, the older the students, the more important the teachers consider promoting analytical skills that are necessary for scientific inquiry (e.g. analysing kinship, differentiating between different types of similarity, analysing phylogenetic relationships). Also, developing the ability to argue scientifically and promoting knowledge about the comparative method as a research method become increasingly important at the middle learning levels (grades 7-10) and upper learning levels (grades 11-13). On the other hand, developing conceptual knowledge and certain types of factual knowledge through comparisons are important aims at grades 5-13 too, in particular knowledge about the ways in which organisms are adapted to their environment, the objective that received the highest scores in this study.

KEY WORDS : comparative method, teachers' aims, scientific inquiry

INTRODUCTION

Scientific inquiry is an opportunity for students to gain insights not only into science concepts and principles, but also into the ways in which scientists think and operate when they acquire knowledge about nature. Classifications of the goals for laboratory instruction clearly reflect these two aspects of practical work in science education, listing among other areas “the promotion of scientific thinking and the scientific method” and “the development of conceptual understanding.”¹ These classifications have contributed significantly to clarifying the role of practical experimental work in science education. In addition, studies investigating the aims that teachers pursue in experiments have provided precise empirical information² so that it is possible, as Hofstein and Lunetta have called for, “to identify optimal activities and experiences from all modes of instruction that will best facilitate these goals”³.

The present study focuses on the comparative method, which is considered a major mode of scientific inquiry by science theorists. Mayr, for example, underlines its importance as an alternative to experimentation and estimates that it has brought forth “more insights than all experiments combined.”⁴ The method’s significance for the advances in biological knowledge, however, contrasts with its marginalised position in educational research. This situation is aggravated by empirical findings revealing that students are confronted with severe problems when they engage in comparative biology, like classifying animals. Students for example misjudge superficial similarity (similar locomotion, similar adaptation to the environment) as indicators of kinship.⁵ Thereby, they disregard that evolutionary *and* ecological factors figure in the concept of similarity and that it is necessary to take them both into account by reflecting upon the criteria that serve as the basis for the comparison.

Comparisons can provide students with opportunities to engage in processes of investigation and inquiry. So far however, there is a lack of empirical information on the question which aims teachers consider important in comparisons, and which instructional modes will facilitate these goals most effectively. The present study aims at clarifying the role of anatomical and morphological comparisons in the classroom. It is conceived as a pre-study and focuses on the aims that teachers pursue when they engage their students in this type of comparison. It is planned that the main study, based on the findings presented in this paper, will test instructional variables expected to enhance the students’ ability to use the comparative method as a way of scientific inquiry. This research project is part of the national quality development program “Increasing the Efficiency of Science and Mathematics Instruction” that addresses key problems of science and mathematics instruction in Germany.

COMPARISONS IN THE TEACHING OF BIOLOGY

The didactic literature lists a broad range of goals for comparisons in biology education.⁶ In contrast to the objectives for experimentation, these have not been systematised yet. For the purposes of this study, a classification was created that deliberately focuses on

¹ L.D. Shulman, P. Tamir, “Research on teaching in the natural sciences”, in R.M.W. Travers, *Second Handbook of Research on teaching*, Chicago, Rand McNally, 1973; and R. O. Anderson, *The experience of science: A new perspective for laboratory teaching*. New York, Columbia University Teachers College Press, 1976.

² Hubertus Meyer, *Experimentelles Arbeiten im Biologieunterricht*, *Friedrich Forum* 3, Seelze, Friedrich, 1987; and Manuela Welzel, Kerstin Haller, et. al., “Ziele, die Lehrende mit dem Experimentieren in der naturwissenschaftlichen Ausbildung verbinden”, *Zeitschrift für Didaktik der Naturwissenschaften*, 4, 1, 1998, 29-44.

³ Avi Hofstein, Vincent N. Lunetta, “The Role of the Laboratory in Science Teaching: Neglected Aspects of Research”, *Review of Educational Research*, 52,2, 1982, 201-217, 213.

⁴ Ernst Mayr, *The Growth of Biological Thought*, Cambridge, M.A., Belknap Press, 1982, 32.

⁵ Ulrich Kattmann, Annette Schmitt, “Elementares Ordnen: Wie Schüler Tiere klassifizieren”, *Zeitschrift für Didaktik der Naturwissenschaften*, 2,2, 1996, 21-38.

two main aspects only: Comparisons as an opportunity for teaching students factual and conceptual knowledge (Set I: Knowledge and Comprehension of Science Contents) and comparisons as an opportunity for familiarising students with basic ways of thinking and operating in science (Set II: Processes of Scientific Inquiry). Klopfer's categories "Knowledge and Comprehension" and "Processes of Scientific Inquiry" were adapted for this purpose.⁷ The items in parentheses concretise these categories and can be found in Table 1 and Table 2.

Set I: Knowledge and Comprehension of Science Contents

- Knowledge of concepts (items 1, 2 and 3 in Table 1)
- Knowledge of specific facts (items 4 and 5 in Table 1)
- Knowledge of classifications, categories, criteria (item 6 in Table 1)
- Knowledge of scientific terminology (item 7 in Table 1)

Set II: Processes of Scientific Inquiry

- Observation of objects and phenomena (item 1 in Table 2)
- Formulation of generalisations warranted by relationships found (item 2 in Table 2)
- Interpretation of observations / scientific argumentation (items 3,4, 6, and 7 in Table 2)
- Knowledge of scientific techniques and procedures (items 5,8, and 9 in Table 2)

RESEARCH QUESTIONS AND HYPOTHESES

This study was designed to find out which aims teachers consider important when they engage their students in anatomical and morphological comparisons. In particular, it is of interest if teachers consider comparisons equally as a source of knowledge of science content and of ways of thinking and operating in science. Also, this study investigates if certain aims shift in importance at different learning levels.

It was expected, roughly, that at the lower learning stages teachers consider the development of knowledge of science contents as more important than providing insights into scientific inquiry because at the early grades the students need to acquire basic anatomical and morphological knowledge. Once this knowledge base is established, it was expected that this relationship be reversed, with knowledge about ways of thinking and operating in science becoming increasingly important also because at the middle and upper learning stages the national curricula assign the topic of evolution greater importance.

METHODOLOGY

The aims teachers consider important in anatomical and morphological comparisons were assessed with a questionnaire that was pre-tested and sent to the 180 schools taking part in the national program "Increasing the Efficiency of Science and Mathematics Education". Participation was voluntary for all teachers. The return rate was 32,5% (n=351).

The teachers were asked to answer a few questions about themselves: 34% of the respondents indicated that they take part in the national quality development program; 56% do not participate (10% missing data). The majority of the respondents (54%) gave the information that they possess more than 20 years of teaching experience, 23 % possess 11-20 years of teaching experience, 8 % possess 5-10 years of teaching experience, 10 % possess less than 5 years of teaching experience (missing data and teacher trainees: 5%). The majority of the respondents (53%) indicated that they teach at the Gymnasium (grades 5-13), the type

⁷ Leopold E. Klopfer, "Evaluation and Learning in Science", in B. Bloom, T. Hastings, G. Madaus, *Handbook*

of school at which students can receive the qualification for further study at a university; 19% teach at the Realschule (grades 5-10), 15% at the Hauptschule (grades 5-9) and 6% at different school types.

In the main part of the questionnaire, the teachers were asked to assess the importance of 26 pre-formulated goals, 16 of which are reported on in this paper while the other ten pursue a different research question. Instead of requesting the respondents to rank the goals from the most important to the least important, a scale of four possible answers (“very often,” “often,” “rarely,” “never”) was used so that it was possible to rate aims as equally important that cannot be hierarchised. This is particularly important because there is a high degree of interdependence between the items from the two sets of objectives outlined above; comparisons can be used for teaching science and *about* science at the same time.

Additional room was provided in case the teachers wanted to add goals to the list that they consider important. However, only very few additions were made. Also, the teachers were asked to answer the questions for one grade only and to indicate which grade they were thinking of when they filled out the questionnaire. They were advised to choose a grade in which they often use anatomical or morphological comparisons, most preferably a grade that they were teaching at that moment or not too long ago. Also, they were asked to indicate the title of the course if they had chosen grades 11-13, which are course-structured.

The data were processed using SPSS to calculate the descriptive statistics (frequencies, means, standard deviations) for the following grade groups: grades 5-6 (early learning levels), grades 7-10 (middle learning levels), and grades 11-13 (upper learning levels). Means were calculated by translating “very often” into 4, “often” into 3, “rarely” into 2, and “never” into 1 so that an objective at a mean of 2,5 is of average importance.

RESEARCH FINDINGS

Table 1 reports on the means and standard deviations of the items in **Set I “Knowledge and Comprehension of Science Contents.”** “Knowledge of adaptations of organisms” is clearly the leading objective in this group, while “knowledge of the evolutionary change of structures” received the lowest scores at grades 5-6 and “knowledge of anatomical terms” ranks the lowest at grades 7-10 and grades 11-13. The majority of items in this set is characterised by slight decreases in importance at the middle and upper learning stages. This is the case for “knowledge of adaptations of organisms”, “knowledge of structure plans”, “knowledge of anatomical facts” and “knowledge of anatomical terms.” Their overall decreases in importance from grades 5-6 to grades 11-13 is 0,32 on average. In contrast, there are two objectives in this set whose importance increases at the middle and higher learning stages: “knowledge of the functions of structures” increases only slightly, but “knowledge of the evolutionary change of structures” increases by 0,72 (cf. Chart 1).

Teachers clearly consider conceptual knowledge—knowledge of adaptations at grades 5-13 and knowledge of functions at grades 7-13—to be more important than other kinds of knowledge. The concept of the evolutionary change of structures is insignificant at grades 5-6, but rises in importance and ranks behind the other two concepts in the third position at grades 11-13. Structural knowledge (structure plans) is rated higher than knowledge of anatomical facts, knowledge of classifications and knowledge of terms across the three learning stages. Knowledge of anatomical facts is still an important aim at grades 5-6, but ranks in the second lowest position at grades 11-13.

Table 1. Teachers' Aims in Anatomical/Morphological Comparisons

Set I: Knowledge and Comprehension of Science Contents [means and (standard deviations)]

Knowledge and Comprehension of Science Contents	grades 5-6	grades7-10	grades 11-13
Knowledge of ...	n=120	n=156	n=71
1. ... adaptations of organisms	3,59 (0,54)	3,38 (0,69)	3,38 (0,64)
2. ... functions of structures	2,98 (0,75)	3,02 (0,76)	3,15 (0,73)
3. ... evolutionary change of structures	2,22 (0,85)	2,62 (0,83)	3,01 (0,75)
4. ... structure plans	3,11 (0,70)	2,84 (0,80)	2,80 (0,78)
5. ... anatomical facts	2,96 (0,74)	2,79 (0,79)	2,49 (0,69)
6. ... classifications of species	2,68 (0,70)	2,61 (0,66)	2,64 (0,72)
7. ... anatomical terms	2,57 (0,73)	2,42 (0,76)	2,29 (0,69)

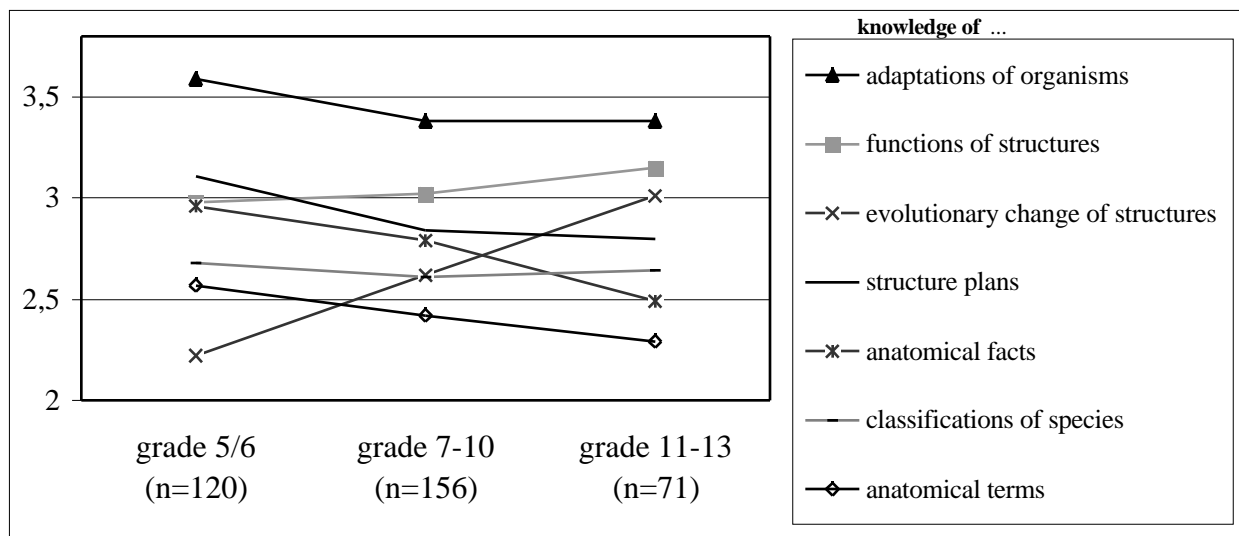


Chart 1. Teachers' Aims in Anatomical/Morphological Comparisons. Set I: Knowledge and Comprehension of Science Contents (lines connecting the means do not carry meaning)

The general tendency for the majority of items in **Set II "Processes of Scientific Inquiry"** is an increase in importance at the middle and higher learning stages (cf. Table 2). This is true for the following objectives: "analysing anatomical structures to assess kinship," "analysing structures to understand the ways in which organisms are adapted to their environment," "scientific argumentation," "distinguishing between different types of similarity (adaptation / common descent)," "reconstructing the phylogeny of organisms," and "discussing research methods" (cf. Chart 2 for this selection of objectives). Their means increase by an average of 0,16 at grades 7-10 and by an average of 0,42 at grades 11-13. "Familiarising students with the method of classifying organisms" shows a slight decrease in importance at grades 7-10, but an overall increase at grades 11-13. The other two items in this set, "close registration of similarities and differences," and "finding common features (generalising)," stay at about the same level of importance across the three learning levels.

Teachers rate the general skills in this set of objectives (i.e. "close registration of similarities and differences" and "finding common features (generalising)") as equally important across the three learning levels. More specific skills concerning the interpretation of perceived differences and similarities are rated higher at the advanced learning levels than at

the middle learning levels and early learning levels. The same is true for objectives concerning knowledge of scientific techniques and procedures. “Discussing research methods” is considered the least important objective in this group at the three grade groups.

**Table 2. Teachers’ Aims in Anatomical/Morphological Comparisons
Set II: Processes of Scientific Inquiry [means and (standard deviations)]**

Processes of Scientific Inquiry	grades 5-6 n=120	grades7-10 n=156	grades 11-13 n=71
1. close registration of similarities and differences	3,13 (0,68)	3,09 (0,67)	3,06 (0,72)
2. finding common features (generalising)	2,94 (0,78)	2,85 (0,74)	3,02 (0,72)
3. analysing anatomical structures to assess kinship	2,76 (0,79)	2,84 (0,75)	3,20 (0,65)
4. analysing structures to understand the ways in which organisms are adapted to their environment	2,63 (0,87)	2,79 (0,75)	2,88 (0,63)
5. familiarising students with the method of classifying organisms	2,54 (0,76)	2,44 (0,69)	2,68 (0,71)
6. scientific argumentation	2,47 (0,78)	2,56 (0,73)	3,07 (0,60)
7. distinguishing between different types of similarity (adaptation / common descent)	2,23 (0,85)	2,42 (0,83)	2,90 (0,68)
8. reconstructing the phylogeny of organisms	2,22 (0,88)	2,52 (0,86)	3,00 (0,82)
9. discussing research methods	1,58 (0,67)	1,72 (0,61)	2,30 (0,77)

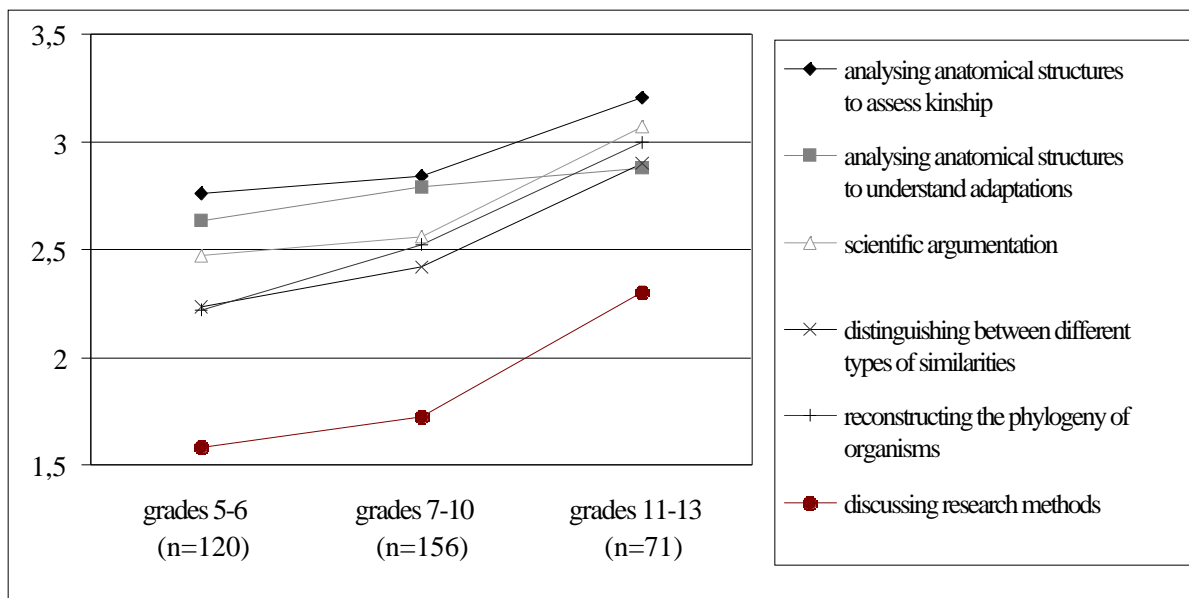


Chart 2. Teachers’ Aims in Anatomical/Morphological Comparisons. Set II: Processes of Scientific Inquiry (selection of six out of nine; lines connecting the means do not carry meaning)

DISCUSSION

The findings substantiate the main hypothesis of this study. Teachers indeed rate the importance of aims in anatomical-morphological comparisons differently at different grade levels, placing less emphasis on scientific inquiry at the early grades than at the upper grades and more emphasis on knowledge and comprehension at the early grades than at the upper grades. Decreases in importance for objectives in Set I: “Knowledge and Comprehension of Science Contents” are however slighter than the gains in importance for objectives in Set II: “Processes of Scientific Inquiry” so that there is no complete reversal of objectives at grades 11-13. Instead, the rise in importance for objectives in Set II: “Processes of Scientific Inquiry” (cf. Chart 2) indicates that the contours of comparisons as a method of scientific inquiry become sharper at the higher learning levels, though comparisons never lose their importance for developing certain kinds of factual/conceptual knowledge (cf. Chart 1). Anatomical-morphological comparisons provide teachers with the opportunity to familiarise students with science contents and basic ways of thinking and operating in science; this potential, however, is more fully exploited at the advanced learning stages (11-13) than at the earlier learning stages.

The findings also highlight some discrepancies. Teachers at the lower grades pursue ecological and classificatory questions in comparisons (cf. items 3, 4, and 5 in Table 2). However, the concept of kinship is divorced from the concept of evolution, as exemplified by the discrepancy between high scores for “analysing anatomical structures to assess kinship” and low scores for “distinguishing between different types of similarity (adaptation / common descent)” (i.e. items 3 and 7 in Table 2; cf. also items 6 vs. 3 in Table 1, and items 5 vs. 8 in Table 2 for further discrepancies between kinship-items and evolution-items). Excluding the evolutionary perspective from comparisons in grades 5-6 is problematic because it interferes with the teachers’ objective to promote methodological knowledge about classification and analytical skills geared towards classifying organisms (i.e. items 5 and 3 in Table 2). Evolutionary factors and ecological factors figure in the often problematic concept of biological similarity that students must tackle when they classify organisms. The problems referred to in the introduction, the students’ deficient differentiation between ecological criteria and evolutionary criteria, can thus be related to the findings in this study. Students need to know more about different kinds of similarity and, more importantly, about the crucial role of criteria in comparative investigations because matching the aims of comparisons with appropriate criteria is at the heart of the comparative method as a mode of scientific inquiry. Enabling students to reflect upon and argue about the criteria that serve as the basis for their comparisons must be more prominent aims at grades 5-10 in order to address the problems students possess in comparisons and in order to give the comparative method a clearer profile as a method of scientific inquiry in the classroom.