To communicate the theory of evolution to all from babies to adults

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Abstract

Teaching evolution is a tricky business. Less teaching seems to give better understanding of the theory. Evolutionary processes are dialectic relations between many actors, individuals, groups, abiotic and biotic factors etc., different from mechanistic descriptions of relations between singular objects in other scientific theories. This difference, in combination with religious beliefs confuses efforts to get understanding and acceptance of the theory of evolution. With the new curriculum for Swedish compulsory school, science education has to be linked to students' own experiences in order to promote critical thinking and skills useable in daily life. Further, biology in science teaching during the first school years is focused on general observations and fundamental concepts, not on scientific methods and evolutionary processes. Thus, students often experience biology as a subject filled with facts about simple relations and teleological explanations, making the theory of evolution superfluous. The objectives here were to design teaching in evolutionary theory adapted to the professional needs of students and to assess the learning outcome. Three different courses in evolutionary theory were included. Two pre-service teacher training programs, for nursery school and for year 4–6 in the compulsory school, and one for students in environmental studies were included. Assessments of learning outcome were made by analyses of texts written by the students. The quality of the science knowledge content and the personal and professional development were assessed by using the 4 R's of Doll. Associations between concepts and understanding were evaluated using clustering and ordination statistical techniques. The learning outcome was good showing visible progressions in the understanding. Thus, it is important to assess the understanding of concepts rather than estimating their frequency in students texts.

Keywords: Evolution, teaching, theory of evolution, teacher training, concepts, assessment

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Introduction

Teaching of evolutionary theory is as problematic as most other teaching since the teacher has to use already well-known concepts in order to introduce new ones. The teacher's knowledge of the background and experiences of the students' is necessary when designing the learning situations as their conceptual profiles determines their understanding of the teaching (Mortimer and El-Hani, 2014). Further, less teaching sometimes seems to give better understanding of the theory of evolution (Sundberg and Dini, 1993, Alters and Nelson, 2002). In addition, the use of pedagogic methods with detailed instructions often confuses the students, making it difficult for them to focus on the theory (Mattsson and Mutvei, 2015).

Furthermore, it has been shown that students find it difficult to grasp the dialectic interrelation between organisms and groups at different levels. The processes on the individual level differ to some extent from the processes of higher taxa. For example, it is important to distinguish between individuals and populations and their respective characters. The biodiversity within a population makes it necessary to use other characteristics of individuals compared to those of groups but this distinction is rarely sustained in discussions and textbooks. Another obstacle is the students' problem with accepting the randomness and meaninglessness in the evolutionary processes and their preferences for more teleological views (Mattsson and Mutvei, 2015).

The processes of organic evolution differ from the common opinion about the nature of most processes in other scientific theories. The evolutionary processes are dialectic relations between many actors, individuals, groups, abiotic and biotic factors continuously influencing each other. This is quite different from the mechanistic descriptions of relations between singular objects in many other scientific theories where a certain stimulus always results in the same response, at least under similar (limited) conditions (Prigogine, 1997). This difference between the theory of evolution and the common simplified opinion about science and scientific theories gives an impression of a theory describing historical events supported by observations of, e.g., fossils to be proved instead of a theory explaining what's actually going on in nature. In combination with religious beliefs or philosophical ideas and images of the human species as the crown creation different from everything else with higher qualities further obstructs all efforts to enhance the understanding and acceptance of the theory of evolution (Mattsson and Mutvei, 2015).

The curriculum for Swedish compulsory school and its syllabus in biology

The new curriculum for Swedish compulsory school (Skolverket, 2011), has changed the role of the teacher from performer and mediator of knowledge to designer and director of learning situations (Mattsson and Mutvei, 2015). The teacher has to design learning aiming to prepare the students to "be able to keep their bearings in a complex reality, where there is a vast flow of information and where the rate of change is rapid. […] It is also necessary that pupils develop their ability to critically examine facts and relationships, and appreciate the consequences of different alternatives." (Skolverket, 2011, p.11). When leaving school each student should have "obtained knowledge about the prerequisites for a good environment and sustainable development" (Skolverket, 2011, p.16).

Applied on the theory of evolution the students should be trained to draw rational conclusions and propose reasonable evolutionary based explanations. Detailed knowledge of evolutionary events becomes less important. This new approach eliminates the problem of students overwhelmed with details concealing major events in evolutionary processes (Alters and Nelson, 2002). Support of this view is also found in the syllabus in biology:

Through teaching, pupils should get an insight into the world view of science with the theory of evolution as a foundation, and also get perspectives on how this has developed and what cultural impact it has had (Skolverket, 2011, p. 105).

Teaching in biology should essentially give pupils the opportunities to develop their ability to: […] use concepts of biology, its models and theories to describe and explain biological relationships in the human body, nature and society (Skolverket, 2011, p. 105–106).

The core content in biology for year 4–6 presents, although not explicitly pronounced, biology based on the theory of evolution as it claims the importance of categorization and grouping of organisms.

Ecosystems in the local environment, relationships between different organisms and the names of common species. Relationships between organisms and the non-living environment. Development of life and adaptation of organisms to different habitats. How animals, plants and other organisms can be identified, categorised and grouped (Skolverket, 2011, p. 107–108).

The body's cells, organs and organ systems and their structure, function and interaction. Comparisons from an evolutionary perspective between man and other organisms. Evolutionary mechanisms and their

outcomes, and also heredity and the relationship between heredity and the environment. […] Scientific theories about the origins of life. The development of life and diversity from evolutionary theory perspectives. How organisms are identified, categorised and grouped, based on relationships between species and their evolution (Skolverket, 2011, pp. 108–109).

When leaving school the knowledge requirements for grade E at the end of year 9 show the minimum level of knowledge and abilities within the theory of evolution:

Pupils have **basic** knowledge of the theory of evolution and other biological contexts, and show this by **giving examples and describing** these with **some** use of the concepts, models and theories of biology (Skolverket, 2011, p. 112).

The actual situation in schools

There are syllabuses for the different subjects from year 4 and one general in science for years 1–3 but no general time plan. Science and technology should be taught 800 hours during the 9 years of compulsory school (Skolverket, 2016b). There is freedom for the teachers, schools or municipalities to distribute the time between the subjects.

The Swedish Schools Inspectorate (Skolinspektionen, 2012) claimed a dominance of biology in science teaching during the first school years. This teaching is often focused on general observations in nature and definitions of fundamental concepts, instead of scientific methods and evolutionary processes. The teaching does not promote understanding of biological theories and the complexity in the interactions on different levels, from cellular to global, and may be one reason why students often use evolutionary concepts incorrectly (Mutvei and Mattsson, 2014) or give teleological explanations to many of their observations (Mutvei, Bollner and Mattsson 2015). As a result of this kind of teaching, students often experience biology as a subject filled with facts about simple relations between individuals which are used for teleological explanations, making the theory of evolution superfluous (Mattsson and Mutvei, 2015).

From our own experience the students' knowledge of evolution is based mainly on facts learnt by heart and reproduced chronologically and if theoretically founded, based on teleological assumptions. Thus, our experiences are in concordance with those of Alters and Nelson (2002).

Objectives

During the last years we have designed, implemented, and evaluated science courses for students with different professional goals. There are differences between the content and the structure of pre-school and primary school teaching which make it necessary to design the pre-service courses for these teachers differently. Similarly, the professional environmentalist differs from the teachers having to know how to adapt evolutionary perspectives on environmental issues and explain these to a broader audience. We had the opportunity to design pedagogical activities to these three groups.

Thus, the objectives were to design and run courses in evolutionary theory adapted to the professional needs of pre-school and primary school teachers and for environmentalists and to assess the learning outcome. It was necessary to identify the essential parts of the theory of evolution, to find a realistic progression in teaching and communicating the theory in different teaching situations, from nursery school to universities and also to adapt it to the coming professional situation of the students.

Material

Student texts from three different courses, that included evolutionary theory was used. The content of the courses differed depending of the future professional focus of the students. Two of the groups participated in pre-service teacher training programs, one for nursery school (n=60) and the other for year 4–6 in the compulsory school (n=25). In these cases the theory of evolution was a part of a wider scientific context including chemistry, physics and technology. The third group consisted of students in the beginning of an environmental study program participating in a course in ecophysiology based on evolutionary explanations (n=65). The aim when designing these courses was to present evolutionary ideas in a form immediately accessible to students at their current level of understanding the theory of evolution, their personal and academic development and to give them the ability to communicate ideas with persons in their future professional environment.

All groups had at least one introductory lecture including Elaine Morgan's TED-talk *The aquatic ape* (Morgan, 2009) and one visit to the Bergius Botanical Garden where the results of different responses of plants to the Mediterranean climate type in different parts of the world were studied. The two groups of teacher students also visited the Natural History Museum and did a practical experiment of natural selection (Working Group on Teaching Evolution, National Academy of Sciences, 1998, p. 78). The pre-school teacher students had other biological activities like field studies and growing seeds but these were not always directly related to the theory of evolution (Table 1). The total time span for these activities was about three weeks and about one third of this time was related to evolution.

Table 1.Course design. Activities included (×) in the three courses.

	Pre-service pre-school students	Pre-service primary school students	Environmental students
Introductory lecture with Morgan TED-talk	×	×	×
Additional lectures	–	×	×
Visit to Bergius Botanical Garden	×	×	×
Visit to Natural History Museum	×	×	–
Field studies	×	×	–
Practical laboratory work	×	×	–
Practical experiment of natural selection	×	×	–
Group projects with oral and written presentations	–	×	×

For the primary school teacher students more lectures and group activities were included and the design was formative. After two weeks the students individually selected areas of further individual studies which should be presented in a written reflection about one week later. Based on these texts all students were given personal instructions of themes they should include in the texts of their final examinations. Out of an integrated approach, including chemistry, we had studied the digestive system and its evolutionary history among animals and the students at this last examination were instructed to give different perspectives on digestion and its evolutionary history (Mutvei, Lönn and Mattsson MS 2017). The time span here was six weeks and about half of the time was used for biology studies.

In contrast to these designs, the environmental students had a more traditional four weeks course with eight lectures, one seminar with discussions and, at one occasion, supervision for a project where they should present short texts about different organisms. Also here we used a formative approach. After two weeks and a half the students made a written examination which was assessed the following day in order to give personal instructions what to think about when writing their texts about the organisms. Here also formative instructions adapted to the specific project groups were included.

Methods

The preliminary selections of the scientific content in the different courses were made according to *Big Ideas of Science Education.* Here mainly idea was number 10: *The diversity of organisms, living and extinct, is the result of evolution* but we decided to use a flipped model compared to the one suggested by Harlen (2015, p. 29). Thus, regardless of the future professional situation of the students we always begun the courses by introducing the concepts of random variation and natural selection and highlighted the importance of the selective forces and the results of their actions. By this design we hoped to avoid teleological explanations and individualistic interpretations which we earlier had seen as a problem (Mattsson and Mutvei, 2015, Mutvei and Mattsson, 2015). Further, the students were included in the course design following the principles of Freeman and Dobbins (2013) which includes effective feedback, a model designed to support the integration of 'feedback' and 'feed-forward' as a social practice. Thus, primary school teacher students and environmental teacher students partly could decide in which direction their studies should turn and were given formative feed-forward during their courses.

The assessments of the learning outcome were made mainly by analyses of student texts including the final examination. The frequencies of biological concepts were recorded. Rubrics presented in advance for the students were used for setting the marks in the examination in biology (Table 2). Further, the quality of the science knowledge content and the personal and professional development were estimated by two teachers scoring 0–3. The quality of their texts was also judged of the students' use of the 4 R's of Doll (1993), *recursion*, *relations*, *richness* and *rigor*. *Recursion* is understanding in depth by the connection of the past with the present through feedback. *Relations is* understanding through network of connections to other things and people. *Richness is* understanding at many levels, to give different interpretations, perspectives and possibilities. *Rigor* is consistently using knowledge in new ways and in new unexpected situations.

Associations between concepts, understanding and quality were visualized using clustering and ordination techniques using the R statistical program (R Core Team, 2016).

Table 2. Material used for assessment

	Pre-service pre-school students	Pre-service primary school students	Environmental students
Written individual examination	×	–	×
Written reflection on themes selected individually	–	×	–
Written project presentation	–	×	×

Results

Pre-school teacher students

At the examination the students should answer one out of three biological questions. Two of these were evolutionary: *The impact of factors on plants and animals*, selected by 20 out of 53 students and *The importance of random variation and natural selection for evolution*, selected by 6. Thus, about 50 % of the students chose to answer these questions. While the third question *Describe the development from seed to mature plant* was answered by 25 students. Two students didn't answer any of the three questions (Table 3).

Table 3. Results of assessment of pre-school teacher students n=51

	Unsufficient (U)	Passed (G)	Better (VG)
Question 1	1	15	4
Question 2	0	3	3
Question 3	1	13	11

In order to pass the task (G) the student had to give a correct description of content, use concepts correctly and describe processes. For the higher mark (VG) the answer should include references to theories, experiments, or observations, together with a familiar but precise language including generalisations.

The formulation of the first question was unfortunate. *Factors* were supposed to mean evolutionary forces. It was mainly interpreted as *processes* by the students and they described photosynthesis (10 answers), climate change (4) or cycles (1). This is the main reason why only four out of 20 students received the higher mark on question 1. All students with higher marks clearly showed how the environment adapted the organisms. The answers of question two and three have a similar distribution of the marks (Table 3.)

Primary school teacher students

The frequencies of concepts used in the texts are on the same level as previously reported (Mattsson and Mutvei, 2016a). Especially, texts with themes selected by the teachers and focused on evolutionary explanations had low frequency of evolutionary concepts (Table 4).

Table 4.Use of concepts in pre-service 4–6 student texts

	Themes selected by students		Themes selected by teachers	
	Full text	Evolutionary parts	Full text	Evolutionary parts
Words	24 973	15 075	32 868	14 195
Biological concepts	653	493	416	291
Evolutionary concepts	268	209	119	92
Frequency of biological concepts	2.61 %	3.27 %	1.26 %	2.05 %
Frequency of evolutionary concepts	1.07 %	1.38 %	0.36 %	0.65 %

There was a significant relation between our interpretation of the students' use of the 4 R's of Doll's (1993) and the marks at the assessment (Figure 1) but also the estimated quality assessed three months later (Figure 2). The frequency of concepts used in the texts did not have any significant influence on the marks of the students or the quality of the text.

Environmental Students

At the examination the students should answer three biological questions: 1) Describe the adaptation to land life of an organism of your own choice and describe at least three important factors behind this adaptation. 2) Explain the structure of the eukaryotic cell out of the theory of endosymbiosis. 3) Describe the adaptation of one animal and one plant to dry, sunny and warm areas regarding water regulation. The results are shown in Table 5.

Table 5. Results of assessment of environmental students (n=62).

	Unsufficient (U)	Passed (G)	Better (VG)
Question 1	17	37	8
Question 2	17	28	17
Question 3	16	36	10

When assessing the written project presentations of different species or species groups, 35 students showed evolutionary references, seven of these to evolutionary processes while 23 did not show any evolutionary perspectives at all. Four students had not presented their projects at time of the assessment.

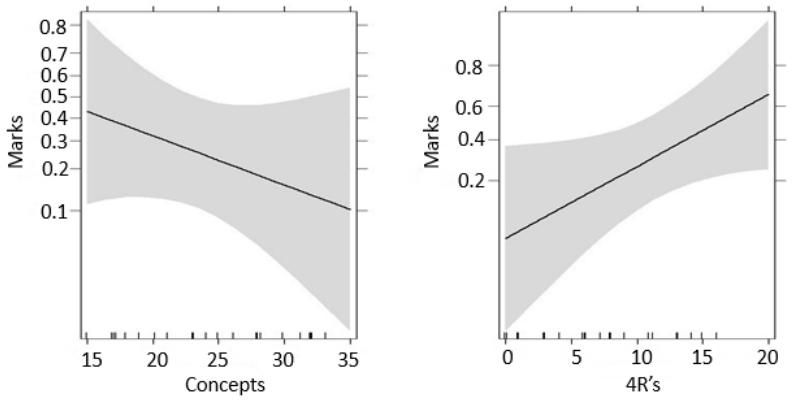

Figure 1. The effect of using the 4 R's or biological concepts on the marks of the final assessment in biology, based on a generalized linear model assuming a binomial error distribution. Only the use of the 4 R's is significant (p= 0.02744 *).

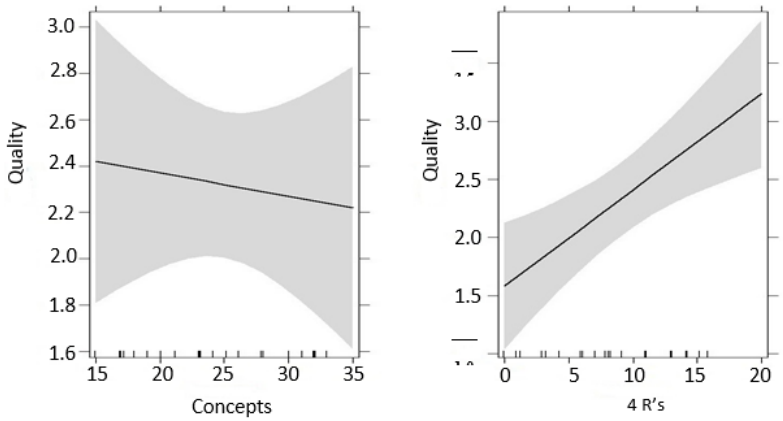

Figure 2. The effect of using biological concepts or the 4 R's on the quality of the final assessment in biology, based on a linear model. Only the use of 4 R's is significant. (p=0.002359 **).

Discussion

In general the learning outcome was good among teacher students. Their courses were intense with compulsory group activities while the environmental students mainly had non obligatory lectures with lower degree of attendance. There were visible progressions in the understanding of evolutionary theory during the courses and at the final examinations most students presented well founded evolutionary explanations to different observations. The descriptions of different evolutionary events were rarely teleological. There were also tendencies to go from reproducing facts or singular examples in the texts to more process-oriented expressions. In concordance with Mutvei, Bollner, and Mattsson (2015) students with high frequency of evolutionary concepts in their texts did not use so many other biological concepts as the others. On the other hand, some students produced good evolutionary explanations using daily life language without using evolutionary concepts.

Pre-school teacher students

The theory of evolution is not included in the curriculum for the pre-school in Sweden (Skolverket, 2011b). It is anyhow important to avoid teleological explanations when studying nature in pre-school. The teachers shall instead use formulations and explanations in concordance with the theory of evolution in order to introduce the theory's framework.

Primary school teacher students

The use of theoretical concepts does not guarantee high quality of the answers or show good understanding (Figures 1 and 2). There also was no significant correlation between the marks assessed by rubrics and the quality evaluation made later, but both the marks and the quality, to a higher extent, were strongly correlated with the recorded use of the 4 R's.

Environmental students

The course for these students was aimed to give an understanding of adaptations on different levels out of a physiological perspective with an evolutionary foundation. The physiological perspective may explain why at the written assessment the answers on the second question showed somewhat better results compared to the others. On the other hand almost the same number of students (45–46) passed all questions. About 40% of the students did not make any references to the theory of evolution in their projects. They may have thought it needless as the course was based on the theory of evolution. As the project ended in a corporate text with all contributions collected this also may have influenced students not to include general information concerning all different organisms.

Conclusions

When students are trained to think evolutionary, they also speak and write in a way that transfers the ideas of the theory of evolution. For future teachers it is important to use a language in concordance to the theory in order to avoid teleological ideas. Furthermore, the emphasis on the use of scientific concepts may be exaggerated. It is not the concept *per se* that is essential but the reality it describes.

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