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LEARNING BIOLOGICAL EVOLUTION DURING ASSESSMENT – EXPLORING THE USE OF AN INTERACTIVE DATABASE-DRIVEN INTERNET APPLICATION

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The overall purpose of our research is to study how students develop understanding of scientific theories, in this study the theory of biological evolution by natural selection. Taking students' preconceptions as the starting point a teaching–learning sequence has been designed, implemented and assessed in a cyclic process. During one trial a group of 18 students (grade 11) was studied using various methods. Just after the theory was introduced, an interactive database-driven Internet problem was used for formative assessment. It deals with the evolution of the length of legs in a population of reindeer and consists of seven parts. The student is at first asked to speculate about the evolution of the length of legs, given a description of its variation. Then more and more information about the actual change in the length of legs and environmental circumstances is presented. The students are offered the possibility of changing their previous answer, as they work through the problem. Already in the opening part of the problem, 16 students answered with scientific evolutionary ideas. Our hypothesis is that if the intraspecific variation is explicitly given, it promotes evolutionary reasoning. The students appreciated the problem, and considered it as an opportunity of learning.

1. Introduction

1.1 The context of this study

A teaching-learning sequence about the theory of evolution has been developed according to a model outlined in figure 1. This model is described in detail by Andersson and Bach (2005), Andersson, Bach, Hagman, Olander and Wallin (2003), and Wallin (2004). The sequence is designed for a compulsory course in biology at the Natural Science Programme of the upper secondary school in Sweden (Hagman, Olander & Wallin, 2002; Wallin, 2004). As a general didactical orientation we take a constructivist view of the knower-known relation as described in the book 'Piaget and knowledge' by Furth (1969).
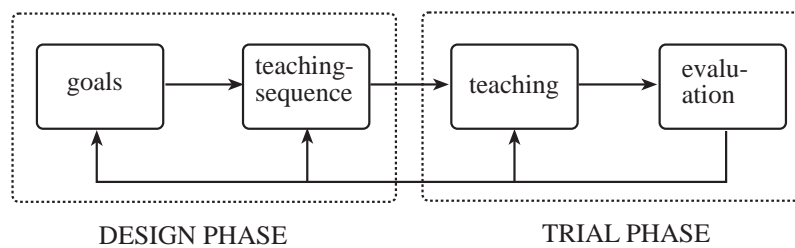

Figure 1. The process of developing a teaching-learning sequence.

Taking students' preconceptions as the starting point the sequence is designed with the aim that students should learn the theory of evolution by natural selection in such a way that it becomes an intellectual tool. In other words they shall be able to describe, understand, explain, and partly predict biological phenomena from an evolutionary point of view.

Different methods were used to evaluate students' knowledge in the area of biological evolution such as a pre-test and interviews before teaching, and problem-solving, writing logbook entries, video recordings of group discussions, interviews, and participant observations during the sequence. At the end of teaching a pen–and-paper test was performed for grading the students. Approximately one year after teaching the students' long-term retention was tested by a delayed post-test. Most methods above were used or could be used for formative assessment. The internet-problem, which is the focus of this paper, turned out to have a high potential as an instrument for formative assessment.

1.2- Formative assessment.

The seminal work of Black and Wiliam (1998) has convinced us that formative assessment, appropriately used, can be of good help in improving teaching and learning. The authors give the following definition:

> *Formative assessment … is to be interpreted as encompassing all those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged.*

The results from the pre-test and interviews before teaching were used for planning the sequence. As the teacher knew the preconceptions of his students he was able to use this knowledge in a deliberate manner in class. He was prepared to meet the students' alternative ideas and used these as a part of the instructional content. The paper-and-pen test and the delayed post-test were in the first place performed for summative assessment, but became formative for improving and planning of the next teaching-learning sequence (see figure 1).

1.3- Aims and research question

In this paper we will describe and discuss results concerning the use of an individual interactive database-driven Internet problem (Wallin & Andersson, 2000). The overall purpose of our research is to study how students develop an understanding of evolutionary biology as a result of teaching. The students' reasoning in different tests was carefully analysed having preconceptions, the conceptual structure of the theory of evolution, and the aims of teaching in mind. This gives insights into those learning and teaching demands that constitutes challenges to students as well as to teachers, when beginning to learn, or to teach evolutionary biology.

Before teaching started for the students discussed in this paper the teaching-learning sequence had been tested, evaluated, and developed twice. During these prior trials students were interviewed. Results from these interviews indicate that if the students are shown the intraspecific variation explicitly they start to discuss different survival rates in acceptable evolutionary scientific terms (Wallin, 2004).

This made us formulate the research question in this paper as a hypothesis: Students will more easily answer evolutionary problems scientifically correct if the existing variation in the population is explicitly shown.

2. Sample and methods

A group of 18 students, age 17 (grade 11), were studied during the teaching-learning sequence about 14 hours long. The students worked with this interactive database-driven Internet application directly after the theory of biological evolution had been introduced and exemplified in class and the time had come for them to begin applying it. It was introduced for several reasons:

- to get information that might be used for detailed planning of the remaining lessons
- to give the students an opportunity to solve an evolutionary problem individually and to reflect on his/her own answers
- to get information about the progress of each student

The problem was introduced and performed in the computer hall of the school. The students answered the different parts individually in front of a computer. The teacher only gave technical assistance and the researcher was observing without any interference. They used between 30 and 45 minutes answering the different parts altogether.

The problem consists of seven parts (Wallin & Andersson, 2000). In figure 2 you can read the first part of the Internet application. After having submitted an answer to part 1 to our database, the student gets new information from the base. He/she can read that there has actually been a change towards more long-legged reindeer and is asked to decide if the previous answer is still valid, and if not or only partly, he/she is asked for a new explanation. After submitting this answer, further information is given. They are told that log-legged reindeer are fast-runners compared to short-legged ones, and the possibility of changing the previous explanation is offered. In part 4 the student is informed that in the same area there is also a population of wolves. Does this fact change his/her explanation? In part 5 the student is asked to discuss the development of the wolf population. Finally, the student's answers to the first five parts are presented by the database and he/she is asked to reflect on his/hers previous answers (part 6). Then a scientific explanation from a text book is given (DeVore, Goethals &

Trivers, 1974). The student is asked to compare this with his/her own answers and to write a comment (part 7). An evaluation form ends the whole problem.

> Long ago a wildlife scientist observed a population of reindeer. She noticed a big variation in the length of their legs. She divided the population into three groups:
>
> - short-legged (20%)
> - somewhat longer legs (60%)
> - long legs (20%)
>
> Let us now imagine that you are visiting this population of reindeer in the same area a great number of reindeer generations later. Use what you have learnt about the theory of evolution to speculate about the length of the legs in the reindeer population at this later moment. Are there still 60 % with long legs and 20 % in the other two groups or have these percentage numbers changed?

Figure 2. The opening part of the interactive database-driven Internet application (Part 1)

The students' written answers were analysed using a category system with qualitatively different levels. Their reasoning was firstly categorized into either alternative or scientific ideas about evolution. Answers with scientific ideas were analysed with respect to the following five evolutionary components (Ferrari & Chi, 1998):

- Random intraspecific variation   'variation'
- Differential survival rate   'survival'
- Differential reproduction rate   'reproduction'
- Genetically determined inheritance   'heredity'
- Accumulation of changes over many generations   'accumulation'

3. Results

Of the 18 students 16 answered the opening part of the problem with scientific ideas about the evolutionary change in the reindeer population (table 1). The numbers of components used of these students vary between two and five. The other two students answered biologically correct but didn't use the theory of evolution and hence no components (table 1; student Ivar and student Martin). All the students had answered with correct or at least acceptable scientific evolutionary reasoning after finishing part 3. Two examples of students' answer to part 1:

> Student Adam: *It will altogether depend on how the environment has changed. If the environment supports long-legged reindeer, these will have the best possibilities of surviving, and their offspring will have genes for long legs, which will bring about longer legs in the reindeer population. But it is equally possible that the environment supports short legs and then they will be the best survivors and get offspring with short legs.* (4 components: variation, survival, heredity, and accumulation)

4

Table 1. The number of scientific components each student is using in the six different parts of the Internet-problem. An arrow means that the student considers his/her previous answer still valid. Answers not containing evolutionary reasoning is marked by a hyphen (-).

Student	Number of scientific components in:					
	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6
Adam	4	→	→	→	5	-
Anna	3	→	→	→	4	1
Berit	5	5	→	→	4	-
Bertil	3	→	→	→	3	-
Cecilia	5	-	4	→	-	-
Doris	3	5	→	→	-	-
Cesar	4	4	2	→	-	-
David	4	3	2	1	-	-
Erik	3	3	→	-	-	1
Filip	3	2	2	2	-	-
Gustav	3	→	2	→	-	-
Helge	3	→	2	→	-	-
Elin	3	→	→	-	-	-
Ivar	-	3	→	→	-	2
Johan	2	2	2	→	-	-
Kalle	2	2	→	→	-	3
Ludvig	2	→	→	→	-	-
Martin	-	→	2	→	-	-

In their answers to part 1, few students are specific about environmental factors that might influence the evolution of the reindeer population. One student mentions that long legs might be an advantage when reaching for leaves on trees. A few students point out that long legs might help in escaping predators.

A common suggestion (11 out of 18) is that the proportion of reindeer with 'somewhat longer legs' will increase. Some students explicitly point out that the fact that this group is 60 % of the population indicates that this leg-size is optimal for survival and therefore will be more and more dominant.

In part 4 the students are informed of the wolf population in the same area. The majority of the students (14 out of 18) consider their previous answer still valid. No student use more components in this part than in earlier parts of the problem. In part 5 the students are asked to discuss the development of the wolf population using what they have learned of the theory of evolution so far. No student considers his/her prior answer still valid. Four students give evolutionary explanations with three to five components, all the others answer without evolutionary reasoning.

Student Adam: *The wolf population will probably develop in the way that the wolves which have genes for running fast will be better at catching reindeer now when most of these have become long-legged and can run fast. Therefore the wolves with genes for fast running will be better survivors and can more easily produce offspring since they*

live longer and don't die from starvation. In that way more wolves in the wolf population will become faster. (5 components: variation, survival, reproduction, heredity, and accumulation)

Despite all students having reasoned in an evolutionary acceptable way about the reindeer population alternative evolutionary ideas are used by some students for explaining the development of the wolf population. For example Student Doris below discusses development in the alternative terms of need and learning.

Student Doris: *Probably they have to learn to run faster. No, but first they will catch the reindeer with shorter legs which are more slow. Surely, it will always be someone born with somewhat shorter legs. But when they 'come to an end', the wolf has to become faster and perhaps becomes more long-legged so it runs fast. They will probably find out some smart way of catching reindeer.* (Alternative ideas: need and learning)

Student Elin discusses evolution in more general terms without mentioning any of the five specific components listed above:

Student Elin: *The wolf will be pleased if the reindeer are born with short legs so they can catch them. But the reindeer will surely get longer legs so they can run faster and the wolves will have difficulties to catch up. Probably the wolf will be extinct if they don't get any food or they become more long-legged too.*

Approximately one year after teaching the students perform a post-test. The maximum score is 60 and the five top results are between 55 and 57. The four students who had discussed the wolf population evolutionary correct are all among the top five students in this delayed post-test.

In part 6 the students get an overview of their answers from the previous five parts and are asked to comment and to add an explanation if they want to. One third of the students doesn't comment at all, one third expresses that they are pleased with their previous answers, and last third choose to add something. Of these students only one (student Kalle) increases the number of evolutionary components (see table 1).

Student Cecilia: *All this is about whether one can manage to think around, and come up with comments of ones own and so on. I think these answers are relatively good but I probably could have used more facts or explanations. But I didn't think it was necessary since it is the same thing! At least as I know it! I feel pleased with it. Simply, the problems were good and so were the answers.*

Student Kalle: *In part 4 I should have written that the slower reindeer will be eaten by the wolves while the ones with long legs, the fast ones, will be better survivors and in that way they can reproduce more times.* (3 components: variation, survival, and reproduction)

In part 7, the students are presented an evolutionary text from an English text book, and asked to compare their own answers with this text. The majority of the students think their own answers are as good or at least almost as good as the one from the text book. Some students point out that they hadn't discussed more than one characteristic of the reindeer, the length of their legs, while the text book also mentions another.

Student Berit: *My answers are more or less in agreement with the authors', except for the fact that I didn't mention the instinct of the reindeer to flee from the wolf. I just keep to the length of the legs. But I do agree that reindeer, which don't flee from wolves,*

wouldn't survive, and that the instinct to flee from wolves therefore will become more common among the reindeers with time.

Student Johan: *I was chocked or something. It was rather well in agreement with what I had said, though I didn't mention the things about genes and all that, but I consider relatively obvious that the child will resemble its parent.*

This problem has an evaluation form at the end. The students are first asked to decide if they experience the problem as interesting or not, easy or difficult, and important or not on a scale from one to five (table 2). They experience the problem as relatively interesting (mean 3.7), neither easy nor difficult (mean 3.2), and fairly important (mean 3.8).

Table 2. The number of students choosing an alternative on a scale from one to five about their experience of this problem.

Scale		Number of students			
1	Boring	0	Difficult	0	Unimportant	0
2		1		2		0
3		5		11		6
4		10		4		9
5	Interesting	2	Easy	1	Important	3

The students are also asked to answer three open-ended questions about the problem. What they thought was good or bad, and how to improve the problem. Many students appreciate that they get the opportunity to think for themselves, and that they are allowed to do changes at the end. One third of the students points out that they don't think anything is bad, but a few students think the different parts of the problem are monotonous.

Student Anna: *You had to think and use the knowledge you had acquired from the lessons.*

Student Kalle: *One learns how different animals have evolved their abilities and then one thinks about how we have evolved in time. The order of the different parts was very good since one can change opinion for the better, when one has seen all the parts on one paper.*

Student Berit: *I think that I have done very many similar tasks, so it begins to be a bit boring.*

Almost half of the students choose to comment, all of them positively, on this problem in their logbook entries at the end of the lesson.

Student Doris: *The things we do with the computers are good. In other words you do it twice. You talk about it, read about it, and after that answer questions about it. That makes it go inside the head and maybe it stays there for a while instead of pushing off out through the other ear.*

Student Cesar: *Good with that Internet thing. You learn to think for yourself. Use yourself the theory of evolution.*

According to the researcher who observed the students while they worked with the problem, the students were concentrated and appeared to take the problem very seriously.

4. Discussion

By finishing part 3 of the problem all our students had answered with scientific evolutionary ideas in at least one part. We think that these results of the students' first attempt to use the theory are good, especially in view of the extensive documentation of students' difficulties in understanding the theory of evolution (Anderson, Fisher & Norman, 2002; Bishop & Anderson, 1990; Brumby, 1981; 1984; Demastes, Good & Peebles, 1996; Demastes, Settlage & Good, 1995; Ferrari & Chi, 1998; Jensen & Finley, 1996; Settlage, 1994; Thomas, 2000; Zuzovsky, 1994). One possible explanation can be the nature of the problem, namely the fact that the variation is explicitly given, which we think promotes evolutionary reasoning. In that case the results from this Internet application support the hypothesis of this paper. The intraspecific variation was explicitly given in the problem and all students wrote about different survival of the individuals in the reindeer population. A key condition for reasoning in an evolutionary correct way seems to be awareness of the intraspecific variation.

All students give answers, which are categorized as containing the two components 'variation' and 'survival', but most answers analysed also include one, two, or all three of the other possible components. Many students write quite short answers and it is possible that they have a better understanding than their written answers show. One example of this is Student Johan who writes that he omitted one of the components because he thought it was obvious, in his case 'heredity'. Maybe more students think like him because the 'heredity' component is the one with lowest frequency in the answers, only five students are categorized for reasoning about inheritance.

Concerning the development of the wolf population, only four students discuss this in a scientific evolutionary way, despite being asked to use the theory of evolution. Three of these four students had relatively good preinstructional knowledge, but more interestingly all four are among the five students who have best post-test result one year after teaching. Although there is a positive correlation in result between pre- and post-tests in this group of students (Wallin, 2004), it is interesting to see the really good delayed post-test result of the students who in this problem could see that both populations are evolving at the same time. The teaching had not included any discussions about co-evolution at the time for this problem, and the result informed the teacher that this idea ought to be further developed during lessons to come. These results indicate that it is important to see both populations evolving simultaneously. Next time this problem is used the teacher will investigate if his/her students discuss both populations as evolving. If not, the next lesson will contain such a discussion.

Altogether the students seem to appreciate the problem, and it gives all students time and opportunity to think individually about an evolutionary problem during teaching. In the evaluation form the students express that they appreciate the opportunity to think individually, to be allowed to change their own answers, and to assess their own knowledge. The student evaluation also shows that they had used the problem as an opportunity of learning.

5. Implications

Interactive, database-driven internet applications offer new and flexible ways to arrange assessment for both formative and summative purposes, and in a manner that promotes learning during the assessment. Databases can be made searchable both for teachers and students. Thus individual students can follow their own progress from one assessment to

another by searching the base. If the base is appropriately arranged, both teacher and students can look up the results of the whole class.

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