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EVOLUTIONARY REASONING IN ANSWERS TO TWO QUESTIONS USED TO MEASURE THE DEVELOPMENT OF UNIVERSITY STUDENTS' UNDERSTANDING OF EVOLUTIONARY THEORY

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1 INTRODUCTION

In their everyday life people spontaneously develop concepts describing and explaining their surrounding world. These conceptions, or alternative frameworks (Driver and Easley 1978), or children's science (Osborne, Bell and Gilbert 1983) often conflict with the scientific conceptions and theories taught in school (for a review of the field, see e.g. Driver and Erickson 1983, Duit 1991, and Gilbert and Watts 1983). These are the assumptions behind the research being carried out within the so-called "Alternative Framework Movement" (Gilbert and Watts 1983), where many of the studies have been concerned with describing such alternative conceptions.

The focus in this research tradition has been mainly on students' conceptions in physics. However, there has also been a number of studies concerned with how students conceive various phenomena in the discipline of biology (see Pfundt and Duit 1991 for a bibliography). A subject area which is particularly difficult for students is the mechanism of the evolution of the species. Although students are taught a Darwinian explanation of evolution in school, many persist in maintaining their spontaneously formed teleological or functional explanations of this phenomenon. Similar findings have been noted in other studies: at secondary level by Deadman and Kelly (1978), Engel Clough and Wood-Robinsson (1985), Pedersen (1992), and Pedersen and Halldén (in press); at upper secondary by Halldén and Wistedt (1981) and Halldén (1988); and at university level among students in teacher training by

Pedersen (1985) and among medical biology students by Brumby (1984).

Thus, there is some evidence to indicate that even at the first year of university studies, many students still resort to teleological or functional explanations when confronted with problems concerning the evolution of the species. However, it seems reasonable to expect that students studying biology at the university level will, sooner or later, develop some kind of Darwinian or neo-Darwinian explanation of evolution. In order to describe the process by which this shift in explanation takes place as well as the conceptual context, we designed a study in which students are followed up by means of questionnaires and interviews throughout their academic career in biology, i.e. for three terms (one and a half years) in the Swedish undergraduate system.

In this paper, however, we wish to address a methodological problem in studies of this kind; namely, in what sense do we obtain information about students' conceptions of theoretical principles when we ask them real-life questions, and how does their understanding of the theoretical principles interfere with their knowledge of facts actualised by such questions.

2 ON UNDERSTANDING THE DARWINIAN THEORY OF EVOLUTION

Developing an understanding of evolution is a complex enterprise. To begin with, there is the problem of terminology. Often, we talk about natural selection and adaptation of the *species*, while what we actually want to designate is a *population*. A biological species is defined by individuals who are able to interbreed in the natural state. What we are actually talking about is a "functional species", i.e. populations of the species that are genetically isolated from one another and where the individuals can produce fertile offspring only through human intervention. This terminological ambiguity may make it difficult for the learner to appreciate the important distinction between the level of the individual and the level of the population.

According to Darwin, such as his theory is presented in general textbooks in biology, in the process of speciation, there are three conditions central to natural selection and the adaptation of populations. Firstly, because of limited natural resources, there are more individuals born within a population than can possibly survive. This leads to a struggle for survival among the individuals of the population and only a part of the offspring in each generation will survive. Thus, there are a number of individuals in the population that will not survive and thus will not be able to reproduce. This is called the *struggle for life*. Secondly, the individuals of a population show a wide variation in form and function; no two individuals are exactly alike. Much of this variation is hereditary. The individuals whose inherited characteristics make them best fit for their environment are likely to leave behind them more offspring than do the less fit individuals. Thirdly, this un-equality in the ability of individuals to survive and reproduce will lead to a gradual change in the population with favourable characteristics accumulating over the generations - *natural selection*. . The results of natural selection are the adaptation of organisms to their particular environments. Darwin argued that by cumulative effects over vast expanses of time, natural selection could produce new species from their ancestral forerunners.

In the 1860s, at about the same time Darwin published his book "The Origin of Species", Gregor Mendel discovered the presence of genes and their role in heredity. These findings shed new light on the process of natural selection. This new knowledge was later incorporated under the name of neo-Darwinism into Darwin's earlier theories on natural selection, complementing his original thoughts astonishingly well. Thus, the genetical mechanism conforms to a fourth condition that is central to natural selection.

These are the four factors required in a complete description of the evolution of the species. However, to complicate the picture even more, there have been new findings in recent years about heredity in micro-organisms, such as transposons (mobile segments of DNA) and the movement of genes from one chromosome to another or even between two different species. This new knowledge has led to a need for both students and biologists to revise their understanding of the theory of evolution with regard to bacteria. At present there is no generally accepted theory of evolution for micro-organisms. In courses on evolution it is said nowadays that the neo-Darwinian theory of evolution is only valid for multicellular organisms, i.e. for animals and some plants.

Nevertheless, in studies on learners' understanding of evolution, the first four factors mentioned above appear to be central in determining whether or not a learner's answer is to be classified as "Darwinian" in kind. For example, in order to account for the process of adaptation it is necessary to differentiate between the individual and the population and to keep these two levels separate. On the one hand, by adaptation is meant the result of natural selection, in which case adaptation refers to the gradual change in a population caused by the environment. On the other hand, the term refers to the physiological change that takes place in an organism in response to a changing environment, e.g. the acquisition of winter fur in Arctic animals. Biologists also call this latter phenomenon *acclimation* (or *acclimatization*.) Thus, it is the variation between *individuals* that leads to a "natural selection" in their "struggle for life", and this in turn leads to the effect that the *population,* over time, becomes more adapted. The ability to make these distinctions has been identified in earlier studies as a major problem for students (Brumby 1984, Halldén 1988).

As far as it is possible to follow the conditions for classification used in studies on learners' understanding of evolution, it is also these factors which have been central for our decisions as to what extent a learner's answers are to be regarded as "Darwinian". But although the grounds for classifying learners' answers seem to be fairly explicit, in some of the studies researchers still encounter problems in this respect. In a study on how secondary students interpret cases of biological adaptation, Engel Clough and Wood-Robinson (1985) used two different situations as points of departure for their questions. The one situation concerned caterpillars: "In a wood children discovered that most of the caterpillars found on dark tree trunks were dark coloured and most of the caterpillars on the pale trees were pale in colour". The other one concerned foxes: "The Arctic fox lives well at very low temperatures. It has a thick coat of fur, which is obviously very useful in the fox's survival". The students were then asked to explain these situations and their answers were coded according to different categories. For our purpose here, we will point at two of the figures given in the findings. In the first instance, none of the students' answers to the caterpillar problem and 43% of their answers to the fox problem could be placed in the category "Animals adapt in response to a need for change". In the second instance, 50% of their answers to the caterpillar problem and 23% of their answers to the fox problem were placed in the category "Other, including tautological and uncodable responses". As we can see, there were substantial differences in the students' explana - tions of the two situations presented to them. If we look at the higher percentage of tautological and uncodable responses, the caterpillar question seems to have been the more "difficult" question, perhaps because it did not actualise the popular adaptation theme used by 43% of the students in their explanation of the fox problem.

In a later paper, Engel Clough and Driver (1986) comment on the above results. One of their conclusions is that "when tasks probing the same scientific idea are perceived differently by students, and seem not to address the same phenomenon, no consistency of response across contexts is apparent" (p.488) and "the results suggest that there is a range of ways in which given phenomena may be conceptualised" (p.489). The students in our study are of a different age group than those in the above study. Nevertheless, by analysing their responses on two different questions, we hope to shed some light on how a given phenomenon may be conceptualised and, as a result of instruction, how this conceptualisation can be unified, but at the same time with the effect that some responses become more in line with the accepted "correct" answer and others not, depending on the factual knowledge of the students.

3 PURPOSE AND DESIGN OF THE STUDY

To understand the Darwinian theory of evolution demands the understanding of a new way of con-ceptualising the world; so far it can be regarded as the recognition of an entirely new "paradigm" or concept. The failure of students to use such a new model of explanation in order to solve real world problems is often interpreted as a failure to accommodate to the new information. However, the utilisation of this new model for explanation puts demands, not only on the understanding of the explanatory model itself, but on factual knowledge as well. Furthermore, this factual knowledge must be interpretations of phenomena within the new appropriate theoretical framework and not interpretations within the student's already established common sense framework (cf. Halldén 1991). Our purpose here is to explore this state of affairs.

At the beginning of a five-week introductory course in biology, first-year students were given a diagnostic test containing questions relating to the theory of evolution of the species. A follow-up was made in connection with the students' examination at the end of that course. Although the students took part in a separate variation of the biology program, all the students had taken the compulsory introductory science course, and had the same admission credits, and could therefore be regarded as comparable. The present paper concerns two of the test questions given to the students (question two was used previously by Brumby 1984).

1. *A central concept in evolutionary biology is "natural selection" (the mechanism of evolution. In his book on the origin of the species, Darwin summarised the process of natural selection as "The survival of the fittest". Explain how you think natural selection functions in relation to the development of organisms and species.*
(Referred to hereafter as the natural selection question).
2. *Scientists have warned doctors of the danger of their increasing use of antibiotics (e.g. penicillin) for treating minor infections. What is the main reason for their concern?* (Referred to hereafter as the antibiotics question).

The students submitted written answers to the test questions. The answers were then transcribed and categorised according to the kind of explanation given and the evidence presented. The categories for coding the students' answers were worked out by the research team collectively, after which the material was sorted independently. In the few instances in which our classifications did not coincide initially, a discussion usually led to agreement. When this was not the case, it was usually because the student's answer lacked sufficient information, for which reason it was classified as "nonsensical".

4 RESULTS

4:1 THE NATURAL SELECTION QUESTION

The students' answers to the natural selection question are summarized in Table 1. In order to see in what way the students' answers corresponded with the central components in the Darwinian theory of natural selection as related above (Part 2), we analysed their answers for the following evidence:

Category A: A discussion of the *struggle for life*. More offspring are produced than can survive on available resources. *Category B:* A variation exists among individuals in the population that is hereditary. *Category C.*: Mutation as the mechanism responsible for the variation discussed. *Category D:* "Adaptation only". The individual or population has become adapted. Although the "struggle for life" and mutations may be <u>mentioned</u>, there is no discussion of the mechanisms involved in the adaptation. *Category E:* No answer or nonsensical answers.

After the course there is a notable increase of evolutionary reasoning (Cat. A-C) and a comparable strong decrease of "adaptation only" answers (Cat D). The answers also contain a greater number of the categories of natural selection after the course, the percentual sum of categories A-C is raised from 96 to 173 %, i.e. 77 points. About half of this increase (35 points) relates to the discussion of the struggle for life (Cat A).

The students' answers before and after instruction show some notable features. The students wrote rather long elaborated essays, constructing examples using animals or plants in order to explain their ideas. This gave their answers an informal nature. Although the question could be supposed to require rather technical reasoning about the mechanism of evolution, it gave the students more scope, especially before the instruction.

NS before instruction: *Take, for example, a flock of zebra on the plains. The flock contains both males and females, young and old. The zebras that have strong jaws for biting and chewing leaves and grass get the most food and probably grow up to be the strongest. The zebras who can run the fastest can escape more easily from an attacking lion. The strongest males have the best chances to mate with a female and reproduce offspring who inherit their good traits. The males who have bad traits probably won't be able to produce any offspring, and if they do (despite the fact that they are weak and clumsy), then their young will also most likely be clumsy and die early. In this way zebras slowly become more and more flexible and better able to bite off the grass. This was just a couple of examples of traits and causes...*

Table 1. Answers to the natural selection question given before and after the

5-week biology course. The different components of natural selection are separated as well as the "adaptation only" and nonsensical answers. The percentages refer to the number of students.
Since one student may involve several of the categories in his answer, the sum of percentages exceeds 100%.

Evidence discussed	Answer % of N 40 before instruction	Answer % of N 51 after instruction
A: A discussion of the struggle for life. More offspring are produced than can survive on available resources.	38	73
B: A variation exists between individuals in the population that is hereditary.	45	76
C: Mutation as the mechanism responsible for the variation discussed.	13	24
D: Adaptation only. The individual or population has become adapted. Although the struggle for life and mutations may be <u>mentioned</u>, there is no discussion of the mechanisms involved in the adaptation.	48	22
E: No answer or nonsensical answer.	8	6
Total %	152	201

Some students, seemingly not content with the Darwinian mechanistic How-theory of evolution, seem to be looking for the Why-evolution theory of evolution:

NS before instruction *But I'm convinced that there's another factor behind evolution, some kind of "creative force", because if you carry the argument of natural selection to the extreme, back to when the first organisms came into being, the whole idea of "fittest" loses all meaning, because the idea that it would be advantageous for a group of molecules to be in a particular way and interact with each other is an unimaginable theory...*

References of this kind to a superior force or a superior "Law of Nature" do not occur in the an-swers the students give after completing he course. We found no examples of creationists reasoning. At the end of the biology course, the students' answers become more abstract, more like scientific models, and the students seem to have no doubts at all about the theory of evolution as it is presented in books and by teachers:

NS after the course ..*An example of adaptation is the whitish-grey and blackish-grey butterflies that began to turn up in England during industrialization. Before that white butterflies were very common, they couldn't be detected against trees, and so forth. But with industrialization, all the trees, buildings, nature turned greyish black with soot and coal dust. The black-coloured butterflies, which had been uncommon before, made out better than the white-coloured butterflies, which now could be detected much easier. And so the black butterflies became the more common. Adaptation occurs through mutations, generic instinct, through inbreeding, etc....*

Judging by the students' responses, it would appear that the instruction has had some effect. But we cannot yet rule out the possibility that these responses are merely a reflection of rote learning. Let us therefore see how they answered the antibiotics question.

4.2 THE ANTIBIOTICS QUESTION

In order to find out whether the answers we obtained on the natural selection question (Part 4.1) were merely examples of rote learning, the students were asked a second question designed to test their ability to apply their knowledge in a different context. The question we used here had been used earlier by Brumby (1984).

The students' answers are given in Table 2. The evaluation is based on the same kind of evidence we looked for in the natural selection question, described in Part 4:1 above. However, since the students' answers contain very few direct references to the theory of evolution, we have re-coded the categories used in the analysis. We have also taken into consideration what organism the student sees as being the target - man, bacteria or both. Thus, the struggle *for life, natural selection and mutation* categories (Categories

A-C in Table 1) are combined under the category "*Evolutionary thinking*" , and occur with reference to bacteria (Cat. 1) and to man (Cat. 3). References to the effect of antibiotics on both man and bacteria but without accompanying evidence of evolutionary thinking are coded under Category 7. Categories 2 and 4 correspond to Category 4 in Table 1, but a distinction has been made between the referent to man or to bacteria in the students' answers. Table 2 also contains two entirely new categories compared with Table 1. The first, Category 5, contains answers to the effect that penicillin acts on man like a drug or poison, leading to such complications as damage to the body's immune system, allergies, etc. The second new category refers to "Knowledge of recent findings regarding heredity in bacteria", shortened to "Recent findings". Here reference is made in the students' answers to such recently discovered facts as transposons (mobile segments of the DNA) and the movement of genes from one chromosome to another and even between two different species. (There were few indications in the answers to the natural selection question- only 2% -demonstrating that they were aware of these new findings.) This last category is not coded as a separate category, but rather as an aspect of the other categories, indicated in Table 3 as a percentage within brackets. Finally, Table 2 also contains a residue category for incomplete, nonsensical or no answers.

Table 2. Answers to the antibiotics question, before and after a 5-week biology course. The categorisation is based on categories described above divided into target organisms. Answers containing "recent findings" are given within brackets. The percentages refer to number of students. The sum of the percentages exceeds 100, since any one student may involve both target organisms in his or her answer.

Categories	Answer % of N 57 before instruction	Answers % of N 51 after instruction
1 Bacteria Evolutionary thinking	10 (4)	29 (10)
2 Bacteria. Adaptation only	28 (2)	47 (20)
3 Man. Evolutionary thinking	2	2
4 Man. Adaptation only	3	2
5 Man* Antibiotics acts as poison or drug	56	27 (8)
6 No answer and nonsensical answer	9	6
7 Both bacteria and man are discussed.	9	14

* including one answer with a horse stroked by strangles as the target

The students' answers given after the course show a clear shift of focus. Greater attention is given to new findings after the course compared with before the course, particularly the fact that bacteria and not man are the target organisms for antibiotics. References to the immune system and harmful secondary effects on human beings (Cat. 5) decrease from 56% to 27%, while a concentration on the role of bacteria increases from 38% to 76%. Examples of evolutionary and adaptational reasoning also increase. It is interesting to note, however, that in 47% of the cases, the answers given after the course still reflect adaptational thinking, and that only 29% of the answers can be said to consist of a more or less complete Darwinian explanation.

Also, we can see the tendency to focus on man is not abandoned lightly. 31% of the test group (Cat. 3 + 4 + 5) still talk about the effects on man after the course. The increase from 9 % to 14 % in discussing both man and bacteria also underlines this observation.

The secondary category, "*Recent findings about heredity in bacteria*.", increases from 6 to 37 % mainly among the students who see bacteria as the object for the penicillin cure, with a majority in the category "adaptation only".

From these results, it would appear that the antibiotics question is more a test of whether these first-year biology students are aware that penicillin acts on bacteria and not a test of their knowledge of the theory of evolution. Knowing that the target for penicillin is bacteria should actualise the process of evolution, and yet the students' answers contain few references to the mechanism of evolution. Instead, in their answers the students seem to be concerned primarily with the reasons behind the scientists' concern.
... So, using antibiotics leads to the development of resistant bacteria, making penicillin useless, but it also makes the search for new cures even more essential, alternatively more expensive.

...So, we're in a race to the finish against nature, a race that we are prepared to carry to the bitter end, but which we can never win. Our laboratories just don't have the same resources as Nature's laboratories.

These examples indicate that the students have fastened on to the second part of the question (cf. Part 3) and regard the issue as a sociological one rather than as a biological one .

The answers from that half of the students who thought that penicillin acts only on the human body can be divided into two main categories. The first is the idea proposed by 18 students (32%) that penicillin is like a medicine that helps to heal the body and that the repeated use of the drug decreases its positive effect. In their descriptions the students use words like "become immune", "resistant", "used to" and the like. The use of these concepts cannot be related to a conception of evolution because they are not related to any reasoning about heredity.

...The main reason is that you can get used to penicillin, in which case the penicillin no longer has any effect. Antibiotics quite simply lose their effect …

The other main idea, that penicillin is a poison which destroys the human immune system, is shared by 9 students (16%). The students' descriptions of the effect is very similar to a description of the effects of HIV-virus in a human body developing AIDS.

A comparison of the figures we obtained for the antibiotics question put to the students prior to their taking the biology course with those Brumby (1984) obtained from medical students, shows that there is a resemblance in the identification in both sets of replies the same two target organisms - man and bacteria - are identified, but the distribution differs. In our material 29% (line 1+2-7) of the cases contain references to bacteria as the target organism, whereas in Brumby's set the figure was 45% . Further, man is indicated as the target organism in 52% (line 3+4+5-7) of our cases compared with 51% in Brumby's material. There were no instances, in which both man and bacteria were given as the target organism for the antibiotic.

4.3 COMPARISON OF EVOLUTIONARY REASONING IN ANSWERS ABOUT NATURAL SELECTION AND ANTIBIOTICS

4.3.1 Evolutionary and o reasoning in answers to the natural selection question and the antibiotics question after the course.

In Table 1 we observed that in their explanation of natural selection the students included more of the details of Darwinian theory after taking the course than before. From Table 2 we might be tempted to conclude that some of students have indeed learned that the target for antibiotics is bacteria, and they discuss the problem in terms of natural selection. However, in the majority of cases, the discussion is limited to adaptation. This finding requires a more detailed analysis of how students deal with the concepts of selection and adaptation.

For this reason we made a new categorisation of the students' answers. The evidence that formed the basis for the categories in Table 1 was reformulated in the following manner in order of relevance.

1. *Neo-Darwinism*. - the answer contains facts about the struggle for life, natural selection and mutation.
2. *Darwinism*. - the answer contains facts about the struggle for life, natural selection but not to the genom.
3. *Struggle for life and adaptation only*. - the answers refer to the struggle for life. The process of natural selection is presented as a fact; something that has already occurred but there is no description of the underlying mechanism. The population "has become" adapted and the individuals "have become" more fit through mutation.
4. *Incomplete Darwinism*. - one or more of the three points taken to indicate an understanding of Darwinian theory are missing, usually the struggle for life.
5. *Adaptation only*. - the answer is similar to the answers in category 4, but there is no reference to the struggle for life.
6. *Knowledge about recent discoveries regarding heredity in bacteria*. ("Recent findings")- criteria are given above in reference to Table 2.

In Table 3 the answers the students gave to both questions after having completed the biology course have been recoded according to the above categories and presented as percentages. In this comparison only those answers to the first question that take up natural selection and adaptation are included, and for question 2, only those that take up bacteria as the target organism are included. Also, for both questions the residue category (no answers or incomplete, nonsensical answer) is omitted. The percentages of answers containing references to "knowledge of recent findings" is given within brackets.

Table 3. Evidence of evolutionary and adaptional reasoning in the answers students give to the natural selection question and the antibiotic question after completing a 5-week introductory course in biology. References to "recent findings" are given in brackets. The percentages refer to number of students.

Category	Natural selection N = 48	Antibiotics N = 39
1. Neo-Darwinism - contains facts about the struggle for life, natural selection and mutation.	29 (2)	5 (3)
2. Darwinism. - contains facts about the struggle for life and natural selection without reference to the genom.	31	3 (3)
3. Struggle for life and adaptation only - includes the struggle for life. The process of natural selection is presented as a fact; something that has already happened but there is no description of the underlying mechanism. The population "has become" adapted and individuals "have become" more fit through mutation.	17	0
4. Incomplete Darwinism - one or more of the three Darwinian points are lacking, usually the struggle for life.	17	31 (8)
5. Adaptation only. These answers resemble those in category four but lack the discussion of the struggle for life.	6	62 (26)

What emerges from this comparison is the marked difference between how the students tackle the two questions. There is a clear dominance of more or less complete evolutionary answers (60%) to the natural selection question, which according to the results presented in Table 1. is a definite improvement of their evolutionary knowledge obtained after the biology course. However, the stu-dents persist in giving pure adaptational explanations to the antibiotic question (62%). Nearly half of the students refer to "recent findings" about bacteria, and 31 % give an "incomplete Darwin" answer. None of the students propose "struggle for life and adaptation only" as an answer to the antibiotics question.

The students' answers to both questions after the course are more rich in detail. They are written in a more scientific language and are more easy to categorize than the answers that were given before the course.

It is easier to understand what the students mean when they use the term "adaptation" in their an-swers to the antibiotic question:

...It's a case of the bacteria becoming immune if they are exposed too often to antibiotics. The bacteria adapt and develop a resistance to the antibiotic. If you use the antibiotic for slight infections which the body could fight on its own, your laying the groundwork for making it more difficult to combat serious infections.

This example shows that by *adaptation* is here meant *acclimation*, a feature which holds for several of the 62% "adaptation only" answers.

These results may seem at first sight to be somewhat puzzling. On the one hand, the students seem to have a good knowledge of evolutionary theory, but on the other, they give predominantly pure adaptation answers to the antibiotics question.

4.3.2 Students' answers to the natural selection question in relation to their answers to the antibiotics question after the biology course.

The increase of complete answers to the natural selection question after the course, as shown in Table 3, may still be due to learning by rote without proper insight, even in the case of students who gave "good" answers.

In order to study whether there was any profound insight into the concept of evolution, the stu-dents' answers to both questions were studied individually. The students' answers to the natural selection question (the same categories as in Table 3) and their answers to the antibiotics question were examined (same categories as in Tables 2 and 3) and grouped according to how the students answered the natural selection question. The figures are presented in Table 4, where the number of students specifying "recent findings" about bacteria are also given. This is an important piece of knowledge, since the recently discovered facts imply a new or different aspect on the application of natural selection to bacteria.

By comparing the individual student's answers to the two questions, several facts emerge that were not visible when groups of students were compared. The students who give complete neo-Darwinian answers to the natural selection question, i.e., describe the mechanism correctly, show a strong tendency to give a pure "adaptation only" answer to the antibiotics question (8 students of 14). Only one student uses neo-Darwinian reasoning in order to account for the effects of antibiotics on bacteria. Furthermore, a majority of the "neo-Darwinian" students who talk about "adaptation only" with regard to antibiotics include new information about bacteria in their answers (6 students of 8).

If we then look at the students classified as Darwinists with regard to the natural selection question, 7 of 15 talk about "adaptation only" with regard to the antibiotics question and 6 use a form of "incomplete Darwinism" in their explanation of the effects of antibiotics on bacteria. The new information about bacteria in the answers is equally divided between these two groups. The stu-dents who give "struggle for life and adaptation only" answers to the natural selection question produce similar explanations in their answers to the antibiotics question, but the evidence "struggle for life" is dropped almost completely. The students in the "incomplete Darwinism" group also give the same type of answers to both questions. In both groups references to "new findings" about bacteria are sparse (2 students of 16).

Table 4. Students' answers to natural selection question, as categories in Table 3 related to their answers to the antibiotics question, as categories in Tables 2 and 3, after biology course. Students' answers referring "recent kfindings" to bacteria are also given. Answers containing "recent findings" are given within brackets. The figures given refer to the number of students.

Type of answer to natural selection question	Number of students	Type of answer to antibiotics question, number of students
Neo-Darwinism	14 (8)	Neo-Darwinism 1 (1) Adaptation only 8 (6) Man as target 4 (1) No answer 1
Darwinism	15 (7)	Incomplete Darwinism 6 (3) Adaptation only 7 (3) Man as target 2 (1)
Struggle for life and adaptation only	8 (1)	Neo-Darwinism 1 Incomplete Darwinism 1 Adaptation only 5 (1) No answer 1
Incomplete Darwinism	8 (1)	Incomplete Darwinism 4 Adaptation only 1 Man as target 3 (1)

Adaptation only	3 (0)	Darwinism 1 Adaptation only 1 Man as target 1

So far, it looks as if students who know about the recent findings concerning the genetical mechanisms of bacteria quite correctly restrict themselves to talking about adaptation in their answers. There is also evidence to indicate that they use the word *adaptation* in the sense of *acclimation* in their answers to the antibiotic question. Against this, it could be argued, stands the fact that five out of eight students in the group "struggle for life and adaptation only" who give a weak description of natural selection also use "adaptation only" in their answers to the antibiotics question. However, only one of them refers to recent findings about bacteria in their answers.

5. CONCLUDING DISCUSSION

The students' conception of natural selection after having completed the biology course seems to have become, at least to some extent, more profound, judging from the analysis of their answers to the natural selection question given before and after the biology course (Table 1). Among the different pieces of evidence pertaining to natural selection, the most significant increase after the course is that the "struggle for life" is included in the discussions. The tendency to specify hereditary variation also shows a strong increase. The awareness of the struggle for life seems to lead the students into new ways of thinking about natural selection.

The answers to the antibiotics question also reveal a significant change after the biology course. "Recent findings" are incorporated by several students and the target organism is shifted from man to bacteria. This is probably due to new information presented in the introductory course, where the central point is that penicillin acts on bacteria (not on viruses) and that a proper biological reasoning should concern these effects and not the effects on the organism of the human body. This shift of attention, however, does not lead to an extension of answers discussing principles of natural selection as a model for explaining the risks which the increasing use of antibiotics entail (Table 2).

On the contrary, whereas there are good Darwinistic descriptions in these answers to the natural selection question after the course, there is a very strong dominance of "adaptation only" answers in the explanations given to the antibiotics question (Table 3). When the answers to the antibiotics question are examined closely, it is obvious that the "struggle for life" is not mentioned and furthermore, that by the term "adaptation" the students often mean "acclimation". The students obviously did not consider this question to be relevant for discussing competition among bacteria, and so do not use the term "adaptation" in its proper sense, although they seem to have become quite familiar with that concept.

On the face of it, the above mentioned results may seem inconsistent. However, when we compare how the individual students responded to both questions, it appears that those students who appeared to have a profound insight into the concept of evolution, judging from their answers to the natural selection question, mostly gave pure adaptational answers to the antibiotics question (Table 4). Furthermore, most of the students with an elaborated concept of evolution and with pure adaptational answers to the antibiotics question also had incorporated "new findings" about the evolution of bacteria in their answers.

So far, it appears that some of the students have learned quite a lot from the introductory biology course. they seem to have learned a lot about the mechanism of evolution and about the genetical mechanism in bacteria. They also seem to have been socialised into the biologists' view of the world; when confronted with the question of the increasing use of antibiotics, they do not talk about the social, economic and human aspects of the question but rather about bacteria as the target for antibiotics and their description of the effects is quite correct from a biological point of view. But if this is the case, it applies to only 15 of the 48 students accounted fore in Table 4, i.e., for the neo-Darwinists and Darwinists with "adaptation only" answers to the antibiotics question. The next question is how to interpret the other answers.

Five students in the group "struggle for life and adaptation only" gave "adaptation only" answers to the antibiotics question and only one of them mentioned "recent findings" in his answer (Table 4). The adaptationists are correct in their answers, in one sense; they come quite close to a correct biological explanation of the effects of antibiotics on bacteria. But for those four students who were not acquainted with the new findings, the situation is quite different. When they, from their point of view quite correctly, attempt to give a Darwinian explanation of the effects on bacteria, their answers have to be regarded as rather poor ones. We cannot establish whether they choose to discuss only the results of the underlying processes, deliberately disregarding information about the mechanism of natural selection and the new findings with regard to bacteria (the mechanism), or if they in fact lack knowledge of these new facts. This actualises a general problem in education that concerns on what basis students decide to regard an answer as complete.

Further, there were 10 students using man as the target for antibiotics after course (Table 4). This could also have been a deliberate choice on the part of the students. There are good reasons for interpreting the question, not as a biological one, but rather as a question concerning the philosophy of methods for medical treatment. In that case the question tells us nothing about the students' knowledge of evolution.

One conclusion which can be drawn from the foregoing is that the antibiotics question does not give us much help in deciding to what extent students understand the Darwinian theory of evolution. One reason is the high incidence of answers where man is the target for antibiotics given by the students even after classroom instruction. But the analysis above also points at other difficulties in presenting real world problems for students as a way of testing their understanding of a scientific concept. One such problem is how do we account for omitted facts. Fragmentary answers cannot without further ado be taken as indicative of a lack of knowledge. They may reflect a deliberate choice by the students as to what parts of a new concept are applicable in an applied example, in our case the antibiotics question. Another problem concerns the students' knowledge of facts. Applying a theoretical principle involves not only mastering the principle in question, but also knowing when it can be appropriately applied. With regard to the antibiotics question discussed here, this appeared to be a crucial point, partly because of recent findings in the discipline of biology. Thus, when we present a real world problem to students, expecting them to apply a theo-retical principle, and then draw conclusions about their understanding of that principle, we are also drawing conclusions about their decisions to apply the principle. To talk about evolution means that you believe that bacteria behave like other organisms; or, to deliberately talk about acclima-tion of bacteria implies that you also know that the neo-Darwinian explanation of evolution is only partly applicable in this case.

When we ask direct questions about theoretical principles, we always stand the risk of receiving responses that mirror verbatim learning only. If on the other hand we ask real life questions, it seems that we in fact are testing much more of the students' knowledge of the theoretical principle in question. Further, we are testing much more than the students' knowledge of the theoretical principle, but also their ability to contextualise problems in the realm of the appropriate scientific subject, i.e. to be masters of a subject matter field. This is not necessarily a weakness in the method. What we hope to achieve by instruction is probably this wider knowledge. Rather, this can explain why we often find the effects of instruction to be rather meagre when we try to measure them with questions about real world problems.
In the introduction we referred to studies on existing alternative frameworks and personal conceptions about evolution among students at the university level, in teacher training by Pedersen (1985) and among medical biology students by Brumby (1984). They concluded that although students are taught a Darwinian explanation of evolution in school, many persist in maintaining their spontaneously formed teleological or functional explanations of this phenomenon. Such a resistance to change explanatory model is not the prevalent result of this study. However, the students' answers are meagre and in the beginning, judging by their written answers, we could categorise the students as "adaptationists" rather than "Darwinists". An explanation to this could, to some extent, be that when confronted with the immense amount of facts about chromosomes, heredity, the Darwinian theory of evolution the students fail to grasp all the ideas (Halldén 1988). So they embrace the phrase "Survival of the fittest" and select the result of natural selection, i.e. the adaptation of species. This meaning of the word, adaptation, is what they find in their textbooks in those parts not treating evolution e.g. the cactuses are adapted to the desert, lungs: respiratory adaptations to terrestrial vertebrates. Watching a television programme about nature or listening to the two of us

giving lectures in our biology fields, again they may hear the word adaptation, without reference to the meaning the concept has in the neo-Darwinian theory of evolution.

To summarise: As beginners the students have an insufficient knowledge of facts and they but them in vague contexts. The learning period at upper secondary level school has probably been too short, which in combination with the superficial approach of their textbooks has prevented them from developing a deeper understanding of the Darwinian theory of evolution. After completing the five-week introductory course in biology, the students have to a great extent become able to include new relevant facts in their answers to the questions and have developed a form of Darwinian or neo-Darwinian explanation of evolution.

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