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Grade 12 students' understanding of adaptation, before and after learning about natural selection.

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ABSTRACT

Adaptation is a concept frequently mentioned in the South African Natural Sciences and Life Sciences curricula, and an important part of evolutionary theory. Evolutionary theory provides a vital explanatory framework for many biological topics and is a principle element in the development of students' scientific literacy – the ability to apply correct scientific knowledge in our everyday lives, or in careers, to improve the quality of lives. Because evolutionary theory underpins and supports an understanding of most biological phenomena and processes, knowledge of evolution-related concepts, like adaptation, is vital for scholars and members of the public if they are to be considered scientifically literate.

This dissertation describes the nature and extent of the ideas held by 90 South African Grade 12 students' from three schools, in terms of their understanding of adaptation and natural selection before and after learning about evolution in Grade 12. Two data collection strategies were used to determine the extent of students' understanding. Written diagnostic activities were completed by students before and after being taught natural selection. Each diagnostic activity had four questions: two were comprehension-level questions on Bloom's taxonomy, requiring students to explain *adaptation* and *natural selection*. The last two questions were application-level questions on Bloom's taxonomy: these scenario-based questions described previously unseen situations and required students to explain how the situations occurred. Students were given equivalent versions of the scenario-based questions before and after instruction. All 16 students from one of the schools were then interviewed after being taught the topic, to probe their answers from the written activities. Open coding and frequency counts were used to analyse open-ended answers from the diagnostic activity and the transcribed interviews, and t-tests and the McNemar variation of the chi square test were employed to check if pre- and post-instruction differences were statistically significant.

The study had five objectives. The first was to establish the nature and extent of scientific concepts in students' answers. Generally, students had a poor understanding of adaptation and natural selection before evolution instruction. In their explanations of *adaptation* before instruction on natural selection students averaged 1.33 correct statements out of the six key concepts considered essential for a correct answer, and only 0.14 correct ideas (on average) when explaining *natural selection*. In the scenario-based questions, students averaged 1.22 correct statements out of the required eight to explain colour changes in peppered moths, and 0.57 correct statements (on average) for a question about changing ear size in elephants, showing that the context of questions had an impact on students' answers. Statistically significant improvements were found for three of the four diagnostic activity questions after instruction. Improvement in students' explanations of *adaptation* were small, increasing from 1.33 to 1.44 ($p = 0.28$), while the average score for the *natural selection* explanations, increased significantly from 0.14 to 0.76 ($p = 0.004 \times 10^{-5}$). For the equivalent versions of the scenario-based questions, students averaged about two correct statements (of the required eight) for both a question on colour change in fruit chafer beetles and a scenario in which seals developed the capacity to stay longer under water: both questions showing statistically significant improvement ($p = 0.003 \times 10^{-3}$; $p = 0.001 \times 10^{-6}$ respectively).

The second objective was to identify the concepts that were missing in students' answers to the diagnostic activity. Many of the key concepts considered to be essential for correct answers were missing from students' explanations. Prior to instruction, more than 80% of students missed at least four of the six correct statements in their explanations of *adaptation*, more than 80% of the students missed all six of the correct statements in their explanations of *natural selection* (five of which were missed by 99% of students), and five of the eight correct ideas were missing in 80% or more of students' answers for both scenario-based questions. After instruction, statistically significant decreases were found in the frequency of missing concepts. For the *adaptation* explanation three of the six statements showed statistically significant reductions in their absence, whilst three statements for the *natural selection* explanation, and six of the eight statements for the scenario-based questions

showed statistically significant reductions. However, the number of missing concepts remained high. More than 80% of students were still missing at least three of the six correct statements about *adaptation;* five of the six correct statements were missed by 80% or more students for the *natural selection* question; and two of the eight were missed by 80% or more in the two scenario-based questions.

The third objective was to determine the nature and extent of students' misconceptions in their responses to the pre- and post-diagnostic activity questions. Students' misconceptions about adaptation and natural selection were frequent and diverse. Of the thirteen most commonly mentioned misconceptions, the idea that *adaptation is caused by environmental change* led the list across all four questions (mentioned 169 times before instruction; 136 after), followed by the idea that *adaptations are caused by an organism's need for them in order to survive* (mentioned 152 times across all four questions before instruction, and 132 after). Six of the thirteen most commonly mentioned misconceptions showed statistically significant reductions after instruction.

The fourth objective was to determine to what extent students used 'alternative frameworks' (scientifically incorrect explanatory frameworks made up of multiple interconnected misconceptions, that seem to influence the way students think about adaptation). While four alternative frameworks noted in the literature were found in students' answers ('evolution on demand', 'survival of the fittest', Lamarckism, and essentialism), the 'evolution on demand' alternative framework was the most common in students' answers, both before and after instruction. However, a statistically significant decrease was seen in the number of students using the alternative framework after instruction (49% of students used it before, and only 30% after: $p = 0.03$). The six misconceptions to do with the 'evolution on demand' alternative framework were also the top six most frequently mentioned misconceptions in students' responses to the diagnostic activities, both before and after instruction. The number of students who used the 'survival of the fittest' alternative framework showed an increase of 10% in frequency after instruction, though this did not prove to be statistically significant (17% before, 27% after, $p = 0.09$). Very few students used Lamarckism (only ten) or essentialism (only three).

The final objective was to investigate students' use of teleological and anthropomorphic thinking in their answers to the diagnostic activities. Teleology (attributing evolutionary changes to need or purpose) was found more often in students' answers than anthropomorphism (ascribing human behaviours or characteristics to animals or inanimate objects). A little more than a third of students used both teleology and anthropomorphism in their explanations of *adaptation*, and about a quarter in their responses to the scenario-based questions. Statistically significant decreases were seen in students' use of teleology when comparing students' answers before and after instruction about natural selection. Students' use of anthropomorphism showed a statistically significant decrease in their explanations of adaptation, but not in their responses to the scenario-based questions. This suggests that teaching about natural selection can decrease students' use of these two unscientific ways of thinking in their explanations of adaptation, even though the two types of wording were not specifically dealt with in class.

This research could be of value to teachers in the following ways. Firstly, it highlights the inextricable link between adaptation and natural selection and the need to teach both topics simultaneously. Secondly, it separates the definition of adaptation and natural selection into a set of key concepts for students to be aware of. Thirdly, it points out common misconceptions (especially those related to the 'evolution on demand' alternative framework) that teachers can aim to confront while teaching adaptation in class. Finally, it points out the potential pitfalls of using certain types of figurative language (especially teleology and anthropomorphism) and how they can inhibit, rather than promote, understanding.