Giraffes Don't Stretch Their Necks Any More: Useful Pieces of Knowledge About Natural Selection

Aditi Wagh and Uri Wilensky

Northwestern University, Chicago, USA

aditiwagh@u.northwestern.edu, uri@northwestern.edu

The purpose of this study was to examine productive pieces of knowledge the middle school children might have about natural selection. In this study, eighth grade students answered questions about two scenarios of natural selection. The test was designed to elicit students' ideas and thinking about how natural selection takes place. The data was analysed from a knowledge-in-pieces framework to identify productive pieces of knowledge that learners used in reasoning about natural selection in a population of butterflies. Results indicate that students are able to draw on some pieces of knowledge that are productive in helping them explain natural selection. The results have implications for the design of learning environments to help students learn about microevolution.

Keywords: Natural selection, Knowledge in pieces, Misconceptions

The Study

Evolution is the primary scientific explanation for the diverse forms of life around us. The importance of understanding evolution is perhaps best illustrated by the title of a paper written by the famous geneticist, Dobzhansky (1973). The title reads, *"Nothing in biology makes sense except in the light of evolution"*. The ubiquitous nature of evolutionary processes in the biological sciences makes it essential for students to have a deep understanding of evolutionary processes and phenomena in order for them to make sense of the diverse forms of life around us.

Despite the importance of this topic, evolutionary mechanisms are notoriously elusive and difficult to understand. There has been a large amount of research examining the nature of misconceptions held by people about evolutionary phenomena and mechanisms. This work suggests that evolutionary misconceptions are robust, persistent and widespread. An alternative to this body of work related to misconceptions is DiSessa's work on "knowledge in pieces" as productive resources for learning (DiSessa, 1993). Along the lines of this work, the present study seeks to analyze students' reasoning about a hypothetical scenario of natural selection to identify productive pieces of knowledge learners might employ in making sense of natural selection.

Literature Review

Natural selection (NS) is one of the key mechanisms of evolution. It describes the process by which an organism survives because of the presence of certain traits, and then successfully reproduces over several generations, making those traits more common in a population over time. Unfortunately, despite the rather simple and elegant nature of natural selection and its role in the evolution of populations of organisms, the concept is difficult to comprehend. There is a tendency to perceive natural selection as an event rather than a process (Ferrari & Chi, 1998; Sinatra, Brem, & Evans, 2008). This categorization of natural selection as an event entails that event-like properties, such as, having a beginning and end, involving a linear sequence, and often progressing toward a specific goal, will be ascribed to it. However, these properties do not align with natural selection which is always occurring within populations and does not head towards a specific goal. Chi (2005) argues that students' misconceptions of emergent processes such as natural selection are robust and resistant to instruction because a deep understanding of emergent phenomena would require an ontological shift from event to process.

Another body of researchers argue that natural selection is difficult to comprehend because it is an instance of an emergent process in which patterns at the level of populations emerge from interactions at the level of an individual. Learners find emergent processes difficult to understand because of slippage between levels whereby students attribute properties or behaviours of an entire population to properties or behaviours of an individual (Wilensky & Resnick, 1999). For instance, when reasoning about a traffic jam, learners are likely to attribute the behaviour of each car that moves forward in a jam to the traffic jam as a whole, which actually moves backward. In short, natural selection is poorly understood at all levels: by the general public, children of all ages and even biology majors (Alters, 2005; Bardapurkar, 2008). Low levels of understanding of evolutionary mechanisms are commonly found among high

school students (Clough & Wood-Robinson, 1985; Demastes, Settlage, & Good, 1995), undergraduates (Bishop & Anderson, 1990), biology majors (Dagher & Boujaoude, 1997), medical students (Brumby, 1984) and science teachers (Affanato, 1986; Osif, 1997). A majority of such work is founded on the premise that people have stable coherent theories about natural selection that do not fit with the scientific explanation of natural selection. Consequently, in order for learning to take place, these researchers suggest that such misconceptions need to be confronted and replaced if they are to be corrected (Alters, 2005; Alters & Nelson, 2002; Ferrari & Chi, 1998; Greene, 1990; Passmore & Stewart, 2002; Seattlage, 1994).

However, this focus on misconceptions has been criticized by another body of researchers who point out that an emphasis on knowledge replacement or correction contradicts constructivist views of learning (Smith, DiSessa & Roschelle, 1993). This emphasis focuses solely on deficiencies in students' knowledge and provides no insight into children's valuable ideas that would serve as resources for learning. By resources, they refer to *"any feature of the learners' present cognitive state that can serve as significant inputs to the process of conceptual growth"* (p. 124). Smith et al. (1994) claim that students have pieces of knowledge, that are useful in some contexts. Though very little work has been done using the "knowledge in pieces" framework to examine student thinking about evolutionary mechanisms, some work does suggest that it offers a useful lens to account for student responses, specifically for inconsistent and incoherent ones (Southerland, Abrams, Cumins, & Anzelmo, 2001). In line with this work, we argue for the need to investigate productive pieces of knowledge that students might have about natural selection.

Research Question

The goal of this study was to explore useful pieces of knowledge that participants draw on while reasoning about natural selection in a hypothetical population of butterflies. By useful pieces of knowledge, we mean ideas that can serve as resources in further learning about this evolutionary mechanism.

Methodology

Data collection and analysis

Data was collected using written tests with questions about natural selection in an eighth grade classroom in a small school in the United States. The words 'natural selection' and 'evolution' were not used in the test. The students' responses were transcribed and coded using a top-down coding approach (Sipe & Ghiso 2004) based on the core ideas of natural selection adapted from Gregory (2009).

Results

The results have been presented in Figure 1. The figure suggests that some knowledge pieces figured prominently in students' explanations of evolutionary change by natural selection than others. Specifically, advantageous and disadvantageous traits of individuals in a population (TR) was one of the pieces that students often drew on in answering the questions. Approximately 53% of total student responses recruited this agent-level component of NS. Students had little difficulty in recognizing that an individual's traits can be advantageous or disadvantageous in relation to its habitat. For instance, when asked to explain why dark coated mice were found in forests, and pale mice in deserts, a student said: *"Mice without fur coats might feel more comfortable and their body heat might be warm and mice with darker fur coats their body heat might be colder"*. This response discussed the mouse's trait in relation to it being beneficial in its environment. However, the trait is not related to chances of survival or death of the individual. About 40% of student responses related the advantageous and disadvantageous nature of a trait to survival or death of an individual in a population. For instance, one student wrote: *"The colour of the mice helps them blend in the area they live in so that their predators cannot find them as easily"*. This response is an instance of the student drawing on her prior knowledge that a trait (colour) is advantageous in their environment because it *"helps them blend in the area"*.

Furthermore, this student made a connection between an advantageous trait and survival of the mice by saying that the camouflage saves them from predators. In general, these two components, *beneficial nature of traits* and *its relation to survival and death*, were the pieces students used most prominently at the risk of ignoring reproduction and perpetuation of genetic traits to offspring. As seen in the graph, only 2% of all responses included the piece about reproduction as also contributing to population change. That is, students discussed survival of individuals with beneficial traits but failed to mention reproduction and passing down of genetic traits as being a complementary mechanism that contributes to population change.

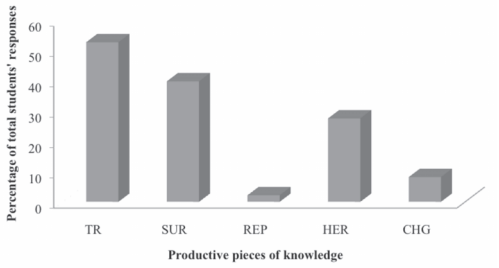

Figure 1: Productive pieces of knowledge

In conclusion, the results suggest that the cognitive resources students had at their disposal in making sense of population change by NS were survival and death of individuals with beneficial and disadvantageous traits respectively. Furthermore, though students possessed cognitive resources about heritability of traits, these knowledge pieces were not utilized in making sense of population change.

Discussion

Our study is an attempt at identifying existing productive pieces of knowledge students might have that help them reason about a scenario of natural selection. Most of the research done about students' understanding of natural selection has focused on the existence of misconceptions about natural selection. This work aligns directly with a replacement model of learning in which learners' incorrect ideas need to be replaced by scientifically accurate ideas.

We do not intend to claim that students do not have any misconceptions about evolutionary mechanisms like natural selection, nor do we claim that students might have a sophisticated understanding of natural selection. Our study is an attempt at investigating the existence of pre-existing pieces of knowledge that might serve as resources when students are learning about natural selection. An analysis and identification of these resources will have implications for the design of learning environments for micro-evolution. In a true constructivist spirit, learning environments could be designed to elicit and build on these resources to help students construct sophisticated understandings of natural selection. For instance, instead of adhering to the confrontation and replacement paradigm of instruction, teachers could elicit students' useful ideas and help them build on these ideas to develop a meaningful understanding of natural selection.

References

Affanato, P.E. (1986). *A survey of biology teachers' opinions about the teachings of evolutionary theory and/or the creation model in the United States in public and private schools*. PhD Dissertation. University of Iowa, Iowa City.

Alters, B. (2005). *Teaching biological evolution in higher education*. Boston: Jones and Bartlett.

Alters, B., & Nelson, C. (2002). Teaching evolution in higher education. *Evolution*, 56, 1891-1901.

Bardapurkar, A. (2008). Do students see the "Selection" in organic evolution? A critical review of the causal structure of student explanations. *Evolution Education Outreach*, 1, 299-305.

Bishop, B., & Anderson, C. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching*, 27, 415–427.

Brumby, M. (1984). Alternative conceptions about the concept of natural selection by medical biology students. *Science Education*, 68, 493–503.

Chi, M. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of Learning Sciences*, 14, 161-199.

Clough, E.E., & Wood-Robinson, C. (1985). How secondary students interpret instances of biological adaptation. *Journal of Biological Education*, 19, 125–130.

Dagher, Z. R., & BouJaoude, S. (1997). Scientific views and religious beliefs of college students: The case of biological evolution. *Journal of Research in Science Teaching*, 34, 429–445.

Demastes, S. S., Settlage, J., & Good, R. G. (1995). Students' conceptions of natural selection and its role in evolution: Cases of replication and comparison. *Journal of Research in Science Teaching*, 32, 535–550.

DiSessa, A. (1993). Towards an epistemology of physics. Cognition and Instruction, 10(2-3), 105-225.

Dobzhanksky, T. (1973). Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher*, 25, 125-129.

Ferrari, M., Chi, M. (1998). The nature of naïve explanations of natural selection. *International Journal of Science Education,* 20, 1231-56.

Greene, E. (1990). The logic of university students' misunderstanding of natural selection. *Journal of Research in Science Teaching*, 27, 875-85.

Gregory, T. R. (2009). Understanding natural selection: Essential conceptions and misconceptions. *Evolutionary Education Outreach*, 2, 156-175.

Osif, B. A. (1997). Evolution and religious beliefs: A survey of Pennsylvania high school teachers. *American Biology Teacher*, 59, 552-556.

Passmore, C., Stewart, J. (2002). A modelling approach to teaching evolutionary biology in high schools. *Journal of Research in Science Teaching*, 39, 185-204.

Seattlage, J. (1994). Conceptions of natural selection: a snapshot of the sense-making process. *Journal of Research in Science Teaching*, 31, 449-57.

Sinatra, G., Brem, S., & Evans, M. (2008). Changing minds? Implications of conceptual change for teaching and learning about biological evolution. *Evolution Education Outreach*, 1, 189-95.

Sipe, L., & Ghiso, M. (2004). Developing conceptual categories in classroom descriptive research: Some problems and possibilities. *Anthropology and Education Quarterly*, 35(4), 472-485. Commentary by F. Erickson, 486 – 493.

Smith, John P. III, DiSessa, A., & Roschelle, J. (1994), Misconceptions reconceived: a constructivist analysis of knowledge in transition, *Journal of the Learning Sciences,* (2), 115–163

Southerland, S., Abrams, E., Cummins, C., & Anzelmo, J. (2001). Understanding students' explanations of biological phenomenon: conceptual frameworks or p-prims? *Science education*, 85, 328-48.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and Technology*, 8(1), 3-19.