Are there educationally critical aspects in the concept of evolution?

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Overview

This paper describes a preliminary investigation into the concepts of troublesome knowledge and thresholds in student understanding within the biology discipline. We propose that evolution represents a threshold concept in the discipline and, consequently, constitutes troublesome knowledge. We sought to explore evolution as a threshold concept in biology using a phenomenographic approach to identify the educationally critical aspects of an understanding of evolution appropriate for undergraduate students. Here we describe the steps in the process whereby we developed the educationally critical aspects from a series of responses to a question about evolution, provided by students entering first year biology at The University of Sydney. The aspects of evolution we identified provide a framework for designing more effective learning activities.

Background

The current definition of a threshold concept was proposed by Meyer and Land (2003) and describes concepts which require an integration of understandings such that ways of thinking are irreversibly changed. Concepts which appear to fit this definition have previously been identified in qualitative studies in biology (Taylor 2006 in press), through a series of interviews with biologists teaching undergraduate courses, and with postgraduate students who had completed biology degree courses. All interviewees identified areas of biology which they, or their students, found troublesome. Initially such concepts appeared to be characterised as being basic principles of biology, generally encountered at a preliminary level. However further discussion of the properties of such concepts brought into question the extent to which they exhibited features of transformation of understanding, inherent in the definition of a threshold (Enwistle in press). Davies and Mangan (2006) have subsequently divided troublesome concepts into a series of categories of increasing complexity, namely basic, discipline and modeling concepts. We now want to explore biology threshold concepts and attempt to fit them into these new categories. However, we still struggle with the specific character of the threshold, and whether there can be distinct aspects of a threshold concept which are identifiable and which represent educationally critical steps that need to be overcome to develop a deeper understanding. In trying to untangle these arguments we needed to work with something which is clearly a threshold in understanding biology, in that it has a transformative role in developing understanding both at a fundamental level and at the more sophisticated 'ways of thinking' level. Entwistle (pers comm.) has postulated that an understanding of evolution involves a transformative change in the way all aspects of biology are viewed and requires a sophisticated integration of knowledge within biology. The concept of evolution is clearly in the thresholds category for both the overall Meyer and Land definition and the Davies and Mangan refinements. In this study we therefore focused on students who were encountering this fundamental biological concept for the first time, and tried to determine what aspects of this concept caused problems in understanding.

Rationale for this study

In 2005 a project investigating the outcomes of changes to the high school biology syllabus in NSW, had examined student responses to a question about the concept of evolution. During this study a hierarchical scale of understanding, based on the SOLO taxonomy (Biggs and Collis 1982), was developed to score student answers to a question about evolution (Taylor, Peat, Quinnell and May in review). These answers provided clear examples of the SOLO prestructural, relational and extended abstract categories, but multi-structural levels of understanding could not be so easily recognised. We therefore hypothesized that the anomaly indicated the existence of an educationally critical aspect of evolution at this level. The notion that a concept has educationally critical aspects which must be addressed by learners to achieve a deep understanding has been described previously (Cope and Prosser 2005; Marton and Booth 1997).

The outcome of Taylor et al.'s (in review) study prompted us to attempt a further analysis of the students' responses about evolution using a framework based on threshold concepts. However, initially similar problems were still encountered when trying to determine where the educationally critical aspects lay in the complex understandings of evolution. At this point an introduction to the use of dimensions of variation in research into the understanding of threshold concepts (Cope 2002, 2004, 2006) allowed us to adopt this approach for our new analysis. Concepts have been shown to have aspects in which understanding of the aspect varies between different levels of understanding of the concept. These aspects are known as dimensions of variation of the concept. Some of the dimensions of variation of a concept are likely to represent educationally critical steps that need to be overcome to develop a deeper understanding This paper therefore describes the process whereby we sought to identify the educationally critical aspects of evolution, using a phenomenographic approach, which created a series of levels of understanding in a matrix of critically different dimensions of variation of evolution.

The analysis

We made an initial analysis of 50 student responses to the following question '*Much of Biology is about the way organisms have become adapted to their environment through the process of evolution. What do you know about adaptation?*' We used a phenomenographical approach (Cope 2004; 2006) to identify levels of understanding in which each higher (deeper) level of understanding is inclusive of all lower levels of understanding (Marton 1994). To define these separate levels of understanding we examined each response and asked the question 'What is the experience of evolution described here?' and documented the features of each response such that the various ways in which evolution could be experienced were described. In this way we developed a matrix containing a number of different dimensions of variation which have different characteristics depending on the level of understanding, as shown in Table 1. As an example, the dimension associated with time is characteristic of the majority of responses, but more complex responses discuss the scale at which change occurs, and develop the links with the processes of change. Once initial levels of understanding and dimensions were decided we analysed another 150 responses to determine if the levels of understanding maintained their rigour. In the next stage of the study we plan to analyse a further 200 responses for a further analysis of, student understanding of troublesome knowledge based on levels of prior knowledge of evolution.

Reflections on the process

Our initial review of the responses, to identify levels of understanding and dimensions of variation, highlighted a number of problems and questions. We were concerned that analysis was hampered by the fact that responses were relatively short, sometimes only a single statement, and many demonstrated the poor English expression skills of some students. However, we decided that the responses were appropriate to the study since they reflected the way in which students are most often asked to demonstrate their understanding of concepts, namely during an examination. We acknowledged that it would have been useful to have the opportunity to interview students about their responses. The ability, or not, of students to articulate their understanding in English remains a problem which cannot be addressed in this study.

During this initial period we also discussed the extent to which we, as reviewers scanning the responses, have expectations of an appropriate answer, and therefore impose our own assumptions of what should be known about evolution. This reinforced our understanding of the need, in phenomenographic research, for researchers to be careful and not impose their own ideas on the data. However, we are aware that the levels of understanding which form the outcome always represent a relation between the researcher and the data.

By focusing on the experience of evolution in the responses, and not the context in which we had asked the question, we found that distinct dimensions of variation of evolution emerged which were experienced in different ways by the students. A key dimension of variation was *time* as was the *role of genetics* in the process. Experiences of evolution relating to *survival of the fittest*, and *natural selection* also appeared. Finally, dimensions of variation involving *different types of evolution and adaptation* and *manipulations relating to evolutionary processes* emerged. A hierarchy of six levels of understanding was described which incorporated some, or all, of these dimensions, as shown in Table 2.

Table 1. Examples of responses which highlight features of the levels of understanding

Levels of understanding 1 and 2
It is a process that takes a long time and occurs through necessity for survival. *Through natural selection, organisms adapt to their environment & thrive.*
Levels of understanding 3 and 4
Adaption occurs due to a change in the environment. It can occur gradually or by punctuation. *I understand adaptation as natural selection, preserving and improving genes while benefit the organism over time.* *Adaptation is genetic and chemical. Darwin proposed much and this was confirmed by Mendel.*
Levels of understanding 5 and 6
Adaptation is the process of a species of organisms changing physiologically, structurally or physically in response to their environment. It occurs over many generations as Darwin proposed. Adaptation is the result of natural selection of a species. *Natural selection agents act on the population. Those who survive do so by chance (the feature that helps them survive is there purely by chance) and gives them an 'adaptive advantage'. It doesn't work the other way ie the animal changing physically to suit the environment eg Lamarck's theory. Yeah, I understand the theory of natural selection*

A review of Table 2 at this point showed that there were still some anomalies which we needed to address. One involved responses which only mentioned *Darwin or Natural selection* with little explanation. Using the Table, these responses were accorded a higher category of understanding than may have been appropriate. However, the creation of the hierarchical levels assumes a certain understanding of concepts associated with *Darwin or Natural Selection* which may not have been explicitly stated. Obviously this is an area where we need to interview students to determine the extent to which this assumption is true. Another problem was discussed which involved responses

Table 2. Levels of student understanding of the concept of evolution as characterised by dimensions of variation (educationally critical aspects of evolution shown in bold)

		Dimensions of Variation				
Category of understanding	Meaning (each category includes characteristics of the preceding levels of understanding)	Process of change in a time framework	Time	Natural Selection and its genetic basis	Variations in adaptive processes	Current and future applications
6	Organismal, population and species responses to change in the environment lead to speciation. Can occur over different time scales and includes human 'manipulation ' of this process	Continuous process of change in response to continuously changing environment	Infinite time frame at species level	Genetic drift, gene flow, influence of mutations leading to speciation, Wallace	**Convergent, divergent punctuated and adaptive radiation and examples of these processes**	**Hybridization and cloning, manipulation of domestic breeds, possible effects of changes due to global warming**
5	Changes in species in response to environmental changes have agenetic basis	Physiological and molecular levels of change	Accumulation of desirable traits	Genetic inheritance, mutations, Mendel, Lamarck	**Theory of punctuated equilibrium**	
4	Darwinian interpretation of change over time leading to perceived differences at species level	Acquisition of favourable traits to survive changing environment	Long periods of time, changes occur in environment and species respond	**Extinction, Darwin, selection in populations**		
3	Species adapt over time in response to changes in the environment, those fittest will survive, others will die out	Process to respond to environment with outcomes of 'advantageous' characteristics	Generation to generation - different offspring	**Natural selection, Survival of fittest**		
2	Species change and adapt to their environment over a long period of time	A gradual process of change	**Over time**	Survival of fittest at basic level		
1	Species change	**A process of change**				

which discussed a dimension of variation as listed in our Table but demonstrated clear misunderstandings of the concept. Originally we had placed such responses in a separate dimension before realising that this did not reflect a separate experience of evolution and could therefore not be so categorised. Cope (pers comm.) explains this in terms of the phenomenographic process, whereby the response is categorised within an appropriate dimension but there is acknowledgment that 'the dimension of variation in this case has an inappropriate value', and the response shows a limited way of experiencing the concept.

We are now undertaking a review of more responses to create a profile of the student cohort in terms of their level of understanding of evolution. This will allow us to confirm the key dimensions of variation in the concept where students have most problems. We will also begin looking for evidence of empirical links between different dimensions of variation. We predict that these linkage points may also constitute educationally critical aspects within this concept. The link between a *process of change* and a *period of time* in which change will occur, would appear to be a fundamental critical aspect, as is the link between the *process of natural selection* and the *genetic underpinning* of the process. These two critical aspects appear at very different levels of understanding of evolution. As such they would probably fall into different categories of concept as described by Davies and Mangan (2005), the former possibly being a basic concept and the latter a discipline concept. Meanwhile another conceptual link is obvious between the dimensions of variation describing the *concept of natural selection* and that describing interlinked *theories of Darwin/Wallace and Mendel*. This link defines a much more sophisticated understanding of evolution and thus would appear to fit Davies and Mangan's definition of a modeling concept, which involves an engagement with ways of thinking and practicing in the discipline i.e., thinking like a biologist. Finally, two other dimensions of variation each describe an application of different types of appropriate biological knowledge to the question. While not necessarily being linked these demonstrate a further educationally critical aspect involving another sophisticated way of thinking and practising as a biologist (Entwistle 2005).

Conclusions

This hierarchical framework developed in our matrix appears to reflect the transformation and integration of ideas required in crossing thresholds in disciplinary knowledge (Meyer and Land 2003). Distinctly different levels of understanding, created during the subsequent re-analysis of student answers, have been shown to incorporate the essential features of evolution (educationally critical aspects). The next stage of our study will investigate how we design learning materials and activities which explicitly demonstrate ways of making links and seeing relationships.

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