2 THE INTERPRETATION OF STUDENTS' LAMARCKIAN EXPLANATIONS

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Abstract

Some years ago we conducted a small scale design research study on the development of the concept of natural selection in upper secondary education. The results of this study were in contradiction with the results from other studies since hardly any Lamarckian explanations were found. In an attempt to explain these results we hypothesized that the occurrence of students' Lamarckian explanations is context-dependant, and that students construct these explanations instantaneously. So the question that required reconsideration was whether students' Lamarckian explanations should be interpreted as representations of available cognitive structures or as context-dependant instantaneous constructions.

Both interpretations were elaborated in an exploratory framework: a 'representation' framework, presuming that students hold stable and consistent conceptions, and a 'construction-in-interaction' framework, presuming that explanations are constructed in interaction, and that students rely on stable, previously acquired basic cognitive structures. This study focuses on the question which of the two frameworks explains the occurrence of students' Lamarckian explanations best. To answer this question, a number of studies reporting students' Lamarckian explanations were analyzed. Our analysis shows that all available empirical evidence can be explained by the 'construction-in-interaction' framework. Some educational implications are discussed in the final section.

1. Introduction

In the last decades, many research studies in science education reported on students frequently holding misconceptions or alternative conceptions. In biology education the best documented example of such a misconception is probably the Lamarckian conception. For a long time it was generally accepted that learning natural selection would require conceptual change of Lamarckian misconceptions (e.g. Bishop & Anderson, 1990).

Following the tradition of design research in Utrecht University, a small scale design research study was conducted (Geraedts & Boersma, 2006) presenting a stepwise development of the concept of natural selection. Data, collected before, during and after the intervention, showed that hardly any Lamarckian explanations. This result is in contradiction with results from many other studies, which reported a frequent occurrence of Lamarckian explanations (e.g. Bishop & Anderson, 1990) It was concluded that the occurrence of students' Lamarckian explanations is context-dependant, and that students construct these explanations instantaneously.

Enderle et al. (2009), in a critical rejoinder on our paper, claimed that 'an extensive body of literature […] has documented the existence and prevalence of a host of misconceptions in a wide array of fields, including Lamarckian misconceptions' (p.2528), and that '…recent pedagogy informed by conceptual change theory has resulted in as much as 50% of subjects achieving more scientific understandings of concepts where learning gains from using more traditional approaches are usually small or non-existent ...'(p.2529). These claims are so contradictory to our results that we were challenged to reconsider the literature mentioned, and address the question how to interpret students' Lamarckian explanations. Should these Lamarckian explanations be interpreted as representations of available cognitive structures or as context-dependant instantaneous constructions?

2. Conceptual framework

Based on the interpretation of the discrepant result of Geraedts and Boersma (2006) it was decided to elaborate two exploratory frameworks: a 'representation framework', presuming that students hold stable and consistent Lamarckian conceptions requiring conceptual change to acquire a neo-Darwinian conception, and a 'construction-in-interaction framework', presuming that Lamarckian explanations are constructed in interaction, and that students rely on stable, previously acquired basic cognitive structures. To avoid confusion, we will explain how the concepts 'conceptual change' and 'Lamarckian conception' are understood, before elaborating further these two conceptual frameworks.

2.1 Conceptual change

In Geraedts and Boersma (op.cit.) classical conceptual change theory was rejected, unfortunately without emphasising that different versions of conceptual change theory can be distinguished (e.g. Demastes, Good & Peebles, 1996; Duit & Treagust, 2003). For a proper

understanding of conceptual change theory it is worth mentioning that the conceptual change theory, as introduced by Nussbaum and Novick (1982) and Posner, Strike, Hewson and Gertzog (1982), was considered an exponent of the so-called 'standard model of conceptual change', which focuses on how change or replacement of paradigmatic conceptual constructs like core concepts or theories can be accomplished. Although Posner et al. (1982) did not introduce conceptual change theory as an empirical prescription of how learning should be structured, many science educators and researchers applied it this way (Demastes et al., 1996). Consequently, many of them followed the original formulation of conceptual change theory, stating that '…learners must experience dissatisfaction with the original conception as well as judge a competing conception to be more intelligible, plausible and fruitful than the alternative in order for the new conception to be used in place of the old' (Demastes et al., op.cit., p. 408). It was this strategy, indeed, that was followed by Bishop and Anderson (1990) in the first conceptual change study in biology education.

Besides the standard model of conceptual change there is a broader view in which conceptual change is not understood as a process of replacement, but as a process of assimilation and restructuring. Duit and Treagust (2003) distinguish two types of conceptual change, variously called weak knowledge restructuring, assimilation or conceptual capture, and strong or radical knowledge restructuring, accommodation or conceptual exchange (p. 672). A good example of this broad view is presented by Demastes et al. (op.cit.), who recognize four patterns of conceptual change, of which only one corresponds with the standard model. In more recent theoretical contributions, the concept of conceptual change is defined at a finer grain size, not as the changes of a concept or conception, but as changes in a coherent set of propositions (diSessa, 2002). Özdemir and Clark (2007) distinguished two broad theoretical perspectives on conceptual change, a knowledge-as-theory perspective and a knowledge-as-elements perspective. This distinction shows the increasing interest in conceptual change at a finer grain size.

Summarizing, what was rejected was the standard model of conceptual change (diSessa & Sherin, 1998), focussing on changing or replacing worldviews or misconceptions by cognitive conflict, and not a conceptual change model that allows accumulation, differentiation, integration and restructuring of finer grained cognitive structures.

2.2 Lamarckian conceptions

To clarify the concept 'Lamarckian conception' we both have to discuss the nature of conceptions, and the criteria required to consider a conception as Lamarckian. We will discuss both issues successively.

Basically, a conception should be understood as a stable and consistent pattern of explanations (Taber, 2000). Consequently, students 'hold' a conception when such a stable and consistent pattern can be inferred from students' spoken or written expressions. For that reason a distinction should be made between students' conceptions and explanations, although most studies presenting empirical data report only on the occurrence of (Lamarckian) conceptions.

In Geraedts and Boersma (2006) explanations were only classified as Lamarckian if they involved individual organisms adapting to biotic or abiotic environmental factors during their lifetime *and* transmitting these changes to their offspring (p. 848). After all, when a student is talking about adaptation, it is often unclear whether he or she is referring to an organism adapting itself to new conditions, or just the species changing over time. Gregory (2009) distinguishes 'soft inheritance' (inheritance of acquired characteristics) from change due to use or disuse of organs, a view explicitly developed by Lamarck. Both categories were mentioned in the study by Bishop and Anderson (1990) and recognised as Lamarckian. Unfortunately, other studies do not always mention criteria to define Lamarckian explanations and it remains uncertain if an explanation classified as Lamarckian meets both criteria.

2.3 Explanatory frameworks

The idea to compare two explanatory models is not new. Southerland, Abrams, Commings and Anzelmo (2001) conducted a study which tested if students' explanations for biological phenomena could be better explained by a so-called mental-model perspective, assuming the stability or consistency of students' reasoning patterns, or a so-called 'knowledge in pieces' perspective based on diSessa's p-prims, defined as spontaneous atomistic knowledge structures (diSessa, 1993). Unfortunately, the results of their study were not conclusive.

Özdemir and Clark (2007, p. 351) questioned if a student's knowledge is most accurately represented as a coherent unified framework of theory-like character, or if it should be considered as an ecology of quasi-independent elements. They concluded that recent empirical evidence is supporting the knowledge-as-elements perspective, although they also recognise that there is support for a knowledge-as-theory perspective.

Empirical evidence supporting the knowledge-as-elements perspective was also found in some studies on the concept 'force' by diSessa, Gillespie and Esterly (2004) and Özdemir and Clark (2009). DiSessa et al. noticed that students' answers were inconsistent across contexts, and that students' understanding of force is context-dependant. It was concluded that these results support the idea that students' knowledge consists of unstructured small elements that are unconsciously activated in certain circumstances. The study of Özdemir and Clark (2009) confirmed these results and showed that small contextual variations may affect students' interpretation.

We will define the two explanatory models somewhat differently than Southerland et al. (2001) and Özdemir and Clark (2007). Both frameworks will be described in more detail to allow evaluatation of empirical data.

The first explanatory framework is the *representation framework*. It presumes that students (1) express a stable pattern of explanations that (2) must be interpreted as representations of available underlying cognitive structures. Thus, in this framework students' Lamarckian explanations are considered as representations of a stable Lamarckian conception. It also predicts that students express consistent Lamarckian explanations.

The stability of students' explanations implies that conceptual change in the classical sense is required when their explanations are scientifically incorrect. This framework underlies the classical conceptual change studies mentioned before. In these classical conceptual change strategies a discrepant event is introduced to evoke dissatisfaction with the existing conception or cognitive conflict, before the introduction of the scientifically correct conception. It is emphasised that the new conception must be intelligible, initially plausible, and fruitful (Duit & Treagust, 1995, p. 62).

The second explanatory framework is the *construction-in-interaction framework*. This framework has two characteristics. It presumes that students (1) construct explanations in interaction that (2) are caused by activation of small, basic cognitive structures. The first characteristic, that students construct explanations in interaction with others (e.g. teachers and peers) and the environment, implies that '…students' explanations are understood to be fluid because they are constructed on the spot, in direct response to the very particular cues of the biological phenomenon and the interview question' (Southerland et al., 2001, p. 343). This first characteristic also implies that emergence of students' Lamarckian explanations may largely be determined by the context, in particular the context set by the teacher or researcher. Finally, it implies that students may construct Lamarckian explanations in one context, while in another context (or at another moment) alternative explanations are constructed.

The second characteristic of the construction-in-interaction framework is that students rely on stable, previously acquired basic cognitive structures that are triggered more or less unconsciously. In the aforementioned studies testing a 'knowledge-in-pieces' perspective, these basic cognitive structures are generally defined as p-prims (diSessa, 1993). In our view however, this is an unnecessary limitation, since literature shows that three empirically grounded approaches to basic cognitive structures can be found. The first approach then is described by diSessa (1993), who reports on the occurrence of fundamental knowledge elements, called phenomenological primitives or p-prims. P-prims are defined as atomistic knowledge structures that are automatically and unconsciously activated by the learner in response to a particular situation (diSessa, 2002).

A second approach on basic cognitive structures is found in the cognitive theory of Lakoff and Johnson (Lakoff, 1987; Lakoff & Johnson, 1999). It emphasizes that the mind is inherently embodied, i.e. that our basic conceptions originate from perception, body movement and experiences with the physical and social environment. Abstract concepts are largely metaphorical, drawing on the structure of our basic conceptions.

A third approach to basic cognitive structures can be found in the extensive experimental and theoretical studies in the field of developmental psychology. Many studies are devoted to categorization and basic concepts like causality, time, space and number. Literature shows that children acquire basic concepts such as causality at an early age, and that their performance improves during primary school age (Corrigan & Denton, 1996).

Explanations based on such pre-existing cognitive components are generally referred to as naïve explanations (e.g. Samarapungavan & Wiers, 1997). However, again we believe that this view is too limited while explanations may not only rely on small, basic cognitive

structures but also on other previously developed and more or less consistent higher order cognitive structures. Consequently, the second explanatory framework does not even exclude a priori the possibility that students develop a Lamarckian cognitive structure.

An implication of this second characteristic is that there seems no reason to expect that available cognitive structures require conceptual change in the classical sense as long as students' small, basic cognitive structures are not in contradiction with the intended scientific concepts. That would imply that a successful learning and teaching strategy, based on gradual, stepwise conceptual development relying on these small, basic cognitive structures, may be interpreted as support for the second framework.

3. Research question

This study focuses on answering the following research question:

Which explanatory framework explains best the occurrence of students' Lamarckian explanations, the 'representation' framework or the 'construction in interaction' framework?

4. Methodology

The description of the two explanatory frameworks indicates that in order to decide which of the two frameworks best explains the occurrence of students' Lamarckian explanations, we have to focus on the following two partial questions:

1. What is the empirical evidence for the consistency of students' Lamarckian explanations?
2. What is the empirical evidence for the effectiveness of classical conceptual change strategies in changing or replacing Lamarckian conceptions?

4.1 The consistency of students' Lamarckian explanations

In order to make a selection of studies reporting Lamarckian explanations we selected first the publications on which Enderle et al. (2009) based their claims, then we consulted the references of these studies, and finally added a small number of other studies reporting students' Lamarckian explanations. Altogether, twelve studies were selected, including Geraedts and Boersma (2006) (see Table 3).

The conclusion that students' explanations are a manifestation of a conception is only warranted if these explanations demonstrate a consistent pattern. Following Taber (2000), a consistent pattern may be inferred if a student's line of reasoning is 'persistent over time and applied coherently across a wide range of overlapping contexts' (p.399). Therefore, we focused our analysis on the data on the consistency of individual students' patterns. Consequently, such patterns could not be inferred from studies recording percentages or

numbers of Lamarckian explanations of a population of students. Therefore, we applied the scheme indicated in Table 1 for analysis of the data:

Table 1. Scheme for analysis of students' Lamarckian explanations

Step 1	Step 2	Step 3
Identification of data about Lamarckian explanations in the selected studies	Numbers or percentages of L. explanations of a population of students	(no further analysis)
	L. explanations of individual students	Consistency across contexts (two contexts or more)
		Inconsistency across contexts (two contexts or more)
		Consistency in time (two moments or more)
		Inconsistency in time (two moments or more)

All data were analyzed by the first author. A selection of data was also analyzed by the second author. Comparison showed no discrepant results.

4.2 The effectiveness of conceptual change strategies

Five studies were found reporting results from classical conceptual change strategies in evolution (Bishop & Anderson, 1990; Demastes et al., 1995; Jensen & Finley, 1996; Jiménez-Aleixandre, 1992; Banet & Ayuso, 2003). Besides our own study (author 1) we found no studies that reported results from other strategies.

Conducting a meta-analysis comparing the effectiveness of classical conceptual change strategies with other strategies would require that only studies are selected that conduct an empirical evaluation of a conceptual change strategy and another alternative strategy with the same objectives and compare the outcomes of both strategies. Unfortunately, only the study of Demastes et al. (1995) meets this criterion. Furthermore, it was noticed that the five studies are rather diverse, i.e. in terms of test conditions, the age of the students, and the instruction methods that were used. Also, the results presented in two of the other four studies are rather incomplete.

A further limitation, linked up with the analysis of the consistency of students' explanations (see section 4.1), is that evidence for the effectiveness of a conceptual change strategy is only found when individual students demonstrate a pattern of Lamarckian explanations and abandon it in favour of a pattern of Darwinian or neo-Darwinian explanations. The only documented shift of a student from Lamarckian to Darwinian explanations was reported by Demastes et al. (1995). That implies that the other studies do not provide direct evidence for conceptual change. Comparing the outcomes of a group of students before and after instruction can only result in indirect evidence. Indirect evidence for the effectiveness of a

conceptual change strategy is demonstrated when the percentage of Lamarckian explanations of a population of students decreases in favour of Darwinian or neo-Darwinian explanations.

Considering these shortcomings and limitations, we concluded that the available studies did not allow for a thorough meta-analysis. Therefore, we summarize only a short characterization of the studies and the conclusions about the effectiveness of the studies as presented by the authors of the studies themselves (see section 5.2).

4.3 Decision rules

We articulated a number of decision rules that were used in deciding which explanatory framework fits best with the empirical data (see Table 2).

Table 2. Decision rules

Criteria	**Decision rules**	
	Representation framework	*Construction-in-interaction framework*
Patterns of Lamarckian explanations	Evidence for consistent patterns of Lamarckian explanations	Evidence showing inconsistency or occasional consistency of Lamarckian explanations
Evidence for the effectiveness of classical conceptual change strategies	Evidence showing the adequacy of classic conceptual change strategies	Evidence showing the adequacy of strategies focusing on stepwise conceptual development

Occasional consistency of Lamarckian explanations indicates that some students or some populations of students may show a consistent pattern of Lamarckian explanations.

5. Results

5.1 The consistency of students' Lamarckian explanations

Our analysis (see Table 3) shows that five studies present percentages of explanations classified as Lamarckian in a population of students instead of the percentage of students giving consistent Lamarckian explanations. Only three studies were found reporting the consistency of students' Lamarckian explanations, although no consistency in time was reported.

Table 3. Consistency of Lamarckian explanations in the selected empirical studies

	Population of students	Individual students		
		Inconsistent	Consistent across contexts	Consistent in time
Brumby (1979)			X	
Kargbo et al. (1980)			X	
Clough & Driver (1985)		X		
Clough & Wood-Robinson (1985)		X		
Halldén (1988)		X		
Bishop & Anderson (1990)	X			
Jiménez-Aleixandre (1992)	X			
Demastes et al. (1995)	X			
Jensen & Finley (1996)	X			
Samarapungavan & Wiers (1997)			X	
Banet & Ayuso (2003)	X			
Geraedts & Boersma (2006)		X		

Two studies (Clough & Driver, 1985; Samarapungavan & Wiers, 1997) focused explicitly on the consistency of students' evolutionary explanations. The results of both studies, however, are contradictory. Clough and Driver reported a low overall level of consistency across contexts. Samarapungavan and Wiers found that 28 out of 35 interviewed primary school children showed consistent explanatory patterns, among which, however, only three were identified as Lamarckian, while most of the children showed consistent non-evolutionary patterns. Inconsistent explanations were also reported by Halldén (1988) and Clough and Wood-Robinson (1985).

The results about the consistency of students' Lamarckian explanations are not conclusive. There is no doubt that Lamarckian explanations are frequently reported. But only three out of ten studies reported students showing consistency of Lamarckian explanations across different contexts. Consistency in time was not demonstrated in any study. On the other hand, four studies explicitly reported on the inconsistency and context-dependence of students' explanations.

5.2 The effectiveness of conceptual change strategies

Bishop and Anderson (1990) reported the results of a pretest-posttest study among college students following an introductory biology course with instruction inspired by conceptual change theory. Although the presentation of data was rather incomplete, it was concluded that the percentage of students able to use the scientific conceptions to explain evolutionary changes increased from less than 25% to over 50%. The authors concluded from these data that their course was moderately successful (p. 415).

The study of Bishop and Anderson was replicated by Demastes et al. (1995) by comparing the results of students following the conceptual change strategy with those of a group of students receiving traditional instruction. The difference between the results of both groups was not significant: both '…methods of instruction failed to promote the construction of a scientific conception' (p. 541).

Jiménez-Aleixandre (1992) reported that significant differences between two groups of students following different conceptual change strategies were found in posttest and retest. Unfortunately however, data of the pretest are hardly reported and pretest, posttest and retest questions are only partly similar. Furthermore, the number of Lamarckian and Darwinian explanations was not presented.

Jensen and Finley (1996) reported the results of a study comparing the results of four different classical conceptual change strategies. If the shift of Lamarckian to Darwinian expressions is considered, the data indicate that the change scores between pretest and posttest varied between 6 and 12 %.

Finally, the most successful study following a traditional conceptual change strategy is presented by Banet and Ayuso (2003). In a pretest, posttest and retention test design the learning outcomes of 14-16 year old students following a course in genetics and evolution was measured. An increase of Darwinian explanations from 8 to 70 %, and a decrease from 86 to 14 % Lamarckian explanations was recorded. In the retention test the number of students presenting Darwinian explanation decreased again to 52 %.

Summarizing, only the study of Banet and Ayuso presents results of a successful classical conceptual change strategy. Their results are comparable with the results of Geraedts and Boersma (2006), showing that 72 % of the students gave consistent neo-Darwinian or Darwinian explanations.

6. Conclusion and discussion

6.1 Conclusions

From our analysis, the following inferences can be made:

1. Empirical evidence for consistent patterns of Lamarckian explanations is not conclusive. Some studies demonstrated consistency, but not consistency in time, while other studies demonstrated inconsistent and context-dependant Lamarckian explanations. The inconsistency of these results can be explained by the construction-in-interaction framework, since it accepts context-dependence.
2. Most classical conceptual change studies reported limited to modest results. The results of the only successful classical conceptual change study are similar to the outcomes of Geraedts and Boersma (2006). Consequently, it should be concluded that there is no evidence that conceptual change strategies are more effective than traditional strategies.

Comparing these results with the decision rules (see Table 1) it can be concluded that the available empirical evidence can be explained by the construction-in-interaction framework and that the representation framework has only a limited explanatory potential.

6.2 The occurrence of students' Lamarckian explanations

Although our analysis shows that there is not sufficient evidence to support the consistency of students' Lamarckian explanations, the question remains why so many students construct Lamarckian explanations in interaction. To answer this question, both internal and external conditions have to be considered, since our model predicts construction in interaction.

From the literature we derived three critical internal conditions for the occurrence of Lamarckian explanations: (1) students' limited experience with evolutionary phenomena (Samarapungavan & Wiers, 1997), (2) students' lack of understanding of the mechanism of sexual inheritance (Kargbo et al., 1980), and (3) students' lack of understanding of the concepts 'population' and 'species' (Halldén, 1988). However, it seems that the occurrence of Lamarckian explanations cannot be explained satisfactory by missing cognitive structures. It may be expected that we have to search for more specific external cues, triggering basic cognitive structures.

Although details about the researchers' questioning behaviour are not reported, some possible external effects may be inferred from the nature of the questions. Questions from studies like Kargbo et al.(1980), related to the effects of external factors on the offspring, show that (1) researchers' questions tend to describe a possible phenomenon occurring in daily life (i.e., the questions are not set in an evolutionary context), (2) the questions deal with inheritance and not with an evolutionary phenomenon, (3) the phenomena presented are not related to the level of the population, and (4) the question itself already suggests that there is an effect on the offspring, which makes it difficult for a student to contradict it.

6.3 Implications for conceptual development

A major implication of the 'construction in interaction' frameworks for conceptual development is that there is no need for conceptual change according to a traditional conceptual change strategy. The framework predicts that students' explanations may emerge by external activation of basic conceptual components. Consequently, students may construct neo-Darwinian explanations under appropriate conditions that activate their interconnected basic conceptual components and to build up from there, until students are able to construct neo-Darwinian explanations for evolutionary phenomena, in different contexts. A metaphor for such a pattern of constructions can be found in dynamic systems theory as elaborated in developmental psychology (Thelen & Smith, 1994), in which the term attractor is used to indicate a behavioural pattern.

An important question that remains open for further investigation is what the nature is of these building blocks that can be used as starting points for conceptual development, and how

a sequence of fine-grained steps can be elaborated. A preliminary answer to this question is found in diSessa's idea of coordination class (diSessa, 2002), consisting of a network of interconnected p-prims. If we extend the idea of p-prims to all propositions the development of the concept of natural selection can be based on a sequence of interconnected propositions from a concept map that represents the concept of natural selection accurately. A comparable procedure is followed in some recent PhD-studies (e.g. Wierdsma, 2012).

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