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HIGH SCHOOL STUDENTS' UNDERSTANDING OF HUMAN EVOLUTION

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Abstract

Diverse alternative conceptions embedded in the minds of learners of biology impede their learning of evolution. Our study aimed to find out the acceptance level of the theory of evolution in high school students in Singapore, characterise how students describe human evolution, and measure the prevalence of common alternative conceptions in the same group of students, through a survey consisting of several multiple-choice questions about their understanding, as well as an open-ended question that allowed students to freely describe how humans have evolved. Student responses were first coded based on the grounded theory approach and then sorted into different categories. The results revealed that a very significant proportion of the students doubted that evolution has ever taken place. Context analyses of their open-ended responses revealed that students preferred to first describe the lineage or taxa of the ancestral organism, followed by trait polarity (both trait gain and trait loss), and subsequently describing trait types. For relatively short evolutionary time, trait loss descriptions were more frequent whereas for relatively long evolutionary time, trait gain descriptions were more likely. Certain types of alternative conceptions, particularly transmogrificationist types of conceptions, were also found to be more prevalent in students' answers, where students grossly overestimates the potential of evolution to drive changes over time. These findings, which were in line with the findings of the literature, further highlight that despite much work done in the education of evolution, students continued to develop alternative conceptions when attempting to understand the theory. As such, there is a need to revise textbooks, curricula, and lesson delivery, especially with respect to the education of human evolution, in order to help students overcome some of these alternative conceptions.

Introduction

Despite decades of emphases and instruction placed onto the teaching of evolution in schools across various countries, it appears that learners' understanding of the concept has not increased (Alters & Nelson, 2002). It is surprising that despite evolution being a theory accepted and supported by many fields of scientific research, many people in various countries still think that evolution is false (Miller *et al.*, 2006). In polls conducted in America over 30 years, the proportion of adults who reject evolution has been stable at between 43 to 47% (Williams, 2009). The topic has continued to pose difficulties for biology students, who develop many misconceptions about how evolution works (Ferrari & Chi, 1998). In addition, it was found that there was no correlation between the acceptance of the theory of evolution and the correct understanding or knowledge of evolution (Sinatra *et al.*, 2003). Students and adults who claim to accept the theory of evolution nonetheless develop various misconceptions in it.

It appears from the availability of reports that misconceptions in evolution are prevalent amongst students (Alters & Nelson, 2002; Ferrari & Chi, 1998). These misconceptions, given various other names such as preconceptions, naïve conceptions or children science, are also termed alternative conceptions (ACs) in this paper. They are the views of young learners that differ significantly from the scientific conceptions described by scientists. Even teachers have been shown to possess ACs in evolution (Nehm & Schonfeld, 2007). These ACs may, according to constructivist theories, interfere with the learning of various other topics in biology that the learner undertakes to learn subsequently, as prior knowledge is the most important factor for learning to be meaningful (Lazarowitz & Lieb, 2006). For the learner, it is therefore essential that these ACs are corrected so that they do not interfere

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with the understanding of other topics in biology that are related to evolution, such as those related to genetics (mutation and variation), biogeography or biodiversity.

The Importance of Understanding Evolution

Evolution as a topic in biology is regarded by many science education researchers as a cornerstone concept (Stern, 2004; Ferrari & Chi, 1998; Martin-Hansen & Michelle, 2008). It has increasingly been included as part of current K-12 Science curricula worldwide, and is regarded as "fundamental to the training of biologists" (McGlynn, 2008; Alters & Nelson, 2002). The many fields of biology connected and guided by the fundamental principles of evolution, led to the declaration that "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973). A poor understanding of evolution as a foundation topic may interfere with how students learn other advanced topics in biology (Nelson, 2007; Lawson & Thompson, 1988; Brumby, 1984). Given the importance of the theory of evolution, it is thus essential that learners understand and accept the basic protoconcepts related to evolution (Jeffery & Roach, 1994), or are at least able to negotiate their naïve theories in light of the scientifically accepted ones.

Science Education and Human Evolution

It is of interest that studies describing how learners understand the evolution of humans are scant. A few studies have done so, but were dealing mainly with soft inheritance and sources of variations (Brumby, 1984; Lawson and Thompson, 1988). This is surprising because in science education, and particularly for biology education, educators have most often opted to use examples of humans or the human body as far as possible to engage and sustain the curiosity, interest and attention of learners (Janssen *et al.*, 2009). There is thus a potential for more work in this area.

It is common knowledge and often reported that chimpanzees are the closest relatives of humans, based on a very high degree of genetic homology between the two species, but the implications for what the statement means to the learner has rarely been explored in the literature (Shtulman, 2006). Our study is unique in providing a window for the learner to describe qualitatively what evolution really means to them, allowing the researcher a view through this window. It also provides a direct opportunity to know if the learner really accepts evolution theory, and/or note the corresponding outcome(s) when they apply the evolution theory in explaining how two groups of descendants (apes and humans) might have shared a common ancestor, and understand how students understand human evolution qualitatively.

It was also observed that for most of the studies conducted, students were given very structured scenarios in order to test for specific ACs. In order to address the difficulties that students encounter with evolution, it might be necessary to obtain deep insights about how they understand evolution without the provision of very structured scenarios (Ferrari & Chi, 1998).

Aims and Objectives

With the primary intention to gain further insights into how students in Singapore understand evolution, this qualitative study was conducted with the following aims:

(1) To find out whether students support the theory of evolution and/or palaeontology
(2) To categorise how students describe human evolution across evolutionary time
(3) To find out how students describe the last common ancestor of humans and chimpanzee
(4) To characterise and describe the prevalence of ACs of students by how they understand human evolution

Research Design

This study aims to gather the qualitative views of grade 12 students on how human ancestors looked like 50,000 years ago, 200,000 years ago, 4 million years ago, 50 million years ago and 1 billion years ago respectively**.** The open questionnaire allows respondents to describe their views freely, according to what they visualise (Hecht *et al.*, 1993).

Participants

A total of 192 Biology students from Innova Junior College (n=74) and Yishun Junior College (n=118) at grade 12 equivalent were surveyed. 34.9% (n=67) of the sample group are males, and 61.5% (n=118) are females (numbers do not total 100% as some did not indicate their gender). The students were aged around 17 to 18 and were grade 12 equivalent. They have already undergone and completed formal lessons on the topic evolution, but not specifically on human evolution.

Data Collection and Analysis

The data was obtained from part of a survey form in which students were asked to respond to two multiple-choice questions and an open-ended question. The two multiple choice questions query respondents on whether they thought that evolution is a factual phenomenon according to the scientific evidence amassed and also whether students thought that palentology (the dating of fossils) is a relatively accurate science (modified from Asghar *et al.*, 2007). Answers that they could select were "Yes", "No" and "Unsure".

The open-ended question is as follows:

"Scientists state that humans and chimpanzees last shared a common ancestor from around 4-7 million years ago. How do you think ancestors of humans would have looked like:

(a) 50,000 years ago? ____________________
(b) 200,000 years ago? ____________________
(c) 4 million years ago? ____________________
(d) 50 million years ago? ____________________
(e) 1 billion (1000 million) years ago? ____________________"

For the open-ended question, data were coded to identify emerging categories based on the grounded theory approach (Strauss & Corbin, 1998). The approach allows categories to arise from the responses through engagement and re-engagement with the raw data. Responses were grouped into categories, and connections between them were studied carefully. Only information relevant for the provision of insights into learners' ACs was further investigated, while other information (which was irrelevant, vague or ambiguous) was not pursued. Such answers included "unsure" and "different".

Responses provided by the survey were transcribed verbatim and examined very carefully, to check for similarities and differences, to group texts and descriptions that are similar conceptually or that indicate common semantic structures into categories. Each text fragment that was grouped into a particular category was repeatedly re-examined to ensure that the decision was sensible, or it would be re-assigned to a different category. Each category was developed to saturation, and was further assigned into sub-categories to allow fine discrimination as required. The frequency of conceptually identical responses was recorded for each category to determine its weighting.

Coding of the responses was completed by the first author and independently coded by another high school teacher who teaches evolution. An in-principle agreement regarding the various categories and sub-categories from the initial coding was reached. Another two high school teachers who teach evolution were then asked to evaluate the validity of the categories and sub-categories to ensure agreement of the grouping and classification.

Two measures, percentage of agreement and Cohen's kappa (K), were used to assess the level of agreement between the two raters. Although the percentage of agreement is most commonly used to assess inter-rater agreement, Cohen's kappa was included as it is regarded as a conservative measure that adjusts for chance agreement by the raters (Cohen, 1960).

Classification of student responses by their contexts is made after reference to the extensive literature documenting assessment item features. Three out of the five reported categories emerged: namely, lineages or taxa descriptions, types of traits, and polarity of trait (trait gain or trait loss) (Nehm & Ha, 2011).

Student responses about how the ancestors of humans looked like at each time point were also re-grouped based on the categories of assessment item features described by Bishop & Anderson (1990), in order to examine the contexts in which these descriptions were made. Also, a differentiation

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was made between "gain of trait", or "loss of trait" for further analyses. Responses that did not fall within any of the categories were placed in the "others" category.

Findings

Support for Evolution and Palaeontology

According to Table 1, 62.6% of the respondents think that evolution is a factual phenomenon. In total, 37.4% of respondents at grade 12 did not support or were unsure about evolution. A similar result was observed regarding the support for palaeontology. Only 61.2% viewed the field as a relatively accurate science while the remaining were either unsure (25.9%) or did not think that it was accurate (12.9%).

Table 1
The Proportion of Students who Accept or Reject Evolution Theory (n=192)

Support for evolution as a factual phenomenon		
Yes (%)	No (%)	Unsure (%)
62.6	18.7	18.7
Support for palaeontology as a relatively accurate science		
Yes (%)	No (%)	Unsure (%)
61.2	12.9	25.9

Contexts of Student Descriptions

Figure 1 shows the categories in which respondents' attempts to describe the ancestors of humans were classified. The total number of valid student responses coded at each time point (50,000 years ago, 200,000 years ago, 4 million years ago, 50 million years ago and one billion years ago) ranged from 249 to 274.

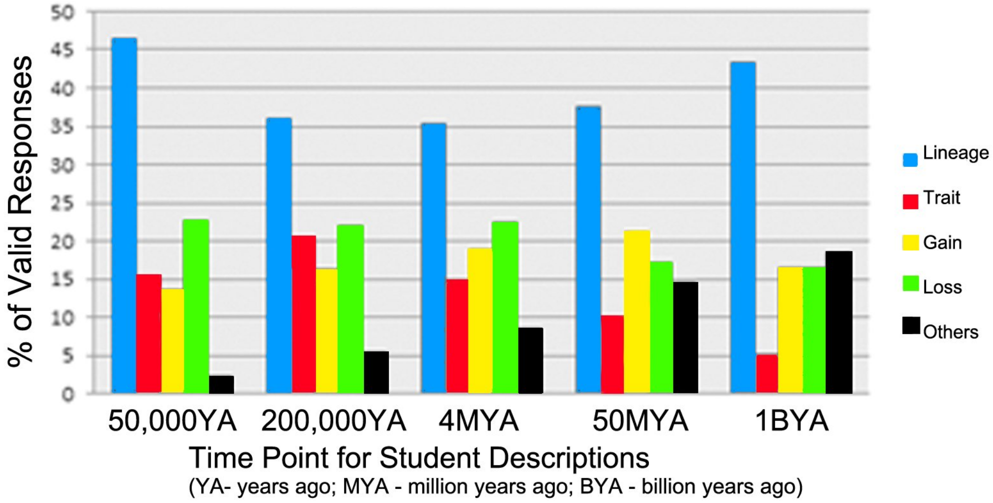

Figure 1. Frequency of student descriptions of human ancestors at each time point

The most dominant descriptions at each time point is the type / lineage of the organism, based on terms such as mammals, primates or chimpanzees, with the proportion ranging from 35.4 to 46.4%. The lowest proportion recorded for this category is for the descriptions 4 million years ago, which coincided with the time frame that students were informed that humans and chimpanzees last shared a common ancestor. At either end of the time frame, lineage descriptions were quite common (over 40%).

Trait descriptions showed large deviations from one time point to the next. The lowest proportion was for the ancestral organism at one billion years ago (5.2%) and the highest was for the ancestral organism at 200,000 years ago (20.5%). Some of the common trait descriptions included "water-living", "hunched" and "bipedal".

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In terms of trait polarity, trait gain descriptions increased steadily from 13.5% at 50,000 years ago to 21.1% at 50 million years ago, remaining relatively high at 16.5% at one billion years ago. Trait gain descriptions that were common were "increases in brain size", "bipedalism" and "gain in height". Trait loss descriptions showed the reverse trend, hovering between 22.0 to 22.6% from 50,000 years ago to 4 million years ago, and decreasing to around 17% at 50 million to one billion years ago. Trait loss descriptions such as "loss of hair", "decrease in muscle mass" and "loss of tail" were common in this category.

The Last Common Ancestor at 4 Million Years Ago

Students' conceptions of the type/lineage of the last common ancestor of both humans and chimpanzees at 4 million years ago were summarised in Table 2. A relatively large proportion of valid responses in this category (31%, category 2) stated that one of the current taxa of extant apes (chimpanzees, orangutans or gorillas) gave rise to the current populations of humans and chimpanzees, although the most common answer was "chimpanzee".

15% stated that the ancestral organism at 4 million years ago (at the time of divergence) was a human / hominid (category 1). A further 10% stated that the ancestor was a hybrid between both the extant species, or a mixed-species community consisting both humans and chimpanzees (category 3). Answers given by students are "half monkey, half human".

Only about 16% of responses most acceptably stated that an ape or ape-like, ancestral animal gave rise to the current populations of humans and chimpanzees (category 6). Within this group, only about 5% used a precise answer such as ape (also regarded as objectionable by some taxonomists according to Pough *et al.*, 1999) or ape-like, while others used answers such as "ancestor" or "different", which were non-committal answers. About 7% of responses stated that the type of organism which gave rise to the current populations of humans and chimpanzees was a primate or monkey (category 4). Answers such as "primate" or "monkey" (category 4) are imprecise but considered marginally acceptable as students have not formally been introduced to primatology and taxonomy studies.

Even more surprisingly, 14.0% of students stated that a non-primate organism (such as a bat or a frog; category 5) was that ancestral common ancestor between humans and chimpanzees, even though the question helped students to focus by stating that the separation between the two species occurred at 4-7 million years ago. Based on Table 2, the proportion of student answers suggesting an inappropriate understanding of human evolution stood at around 61% (categories 1, 2 5 and 8), with only 39% able to give an acceptable (category 6), non-committal (category 7) or marginally acceptable answer (categories 3 and 4), based on the likely interpretations of scientists. Preliminary analysis of the data showed that males and females were quite evenly distributed for each of the categories.

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Table 2

Classification of the Sub-categories for Learners to Describe the "Type / Lineage of Organism" that was the Last Common Ancestor between Chimpanzees and Humans at 4 Million Years Ago

Category	Weighting	Sub-categories	Consistency of agreement	
			% Agreement	K
1. Human	0.15	Human-like (similar) Hominid Human	87.5	0.729
2. Extant Ape	0.31	Chimpanzee Orangutan Gorilla	100	1.0
3. Hybrid	0.10	Hybrid between humans and chimpanzees Both humans and chimpanzees	100	1.0
4. Monkey	0.07	Monkey Primate	100	1.0
5. Non-primate animal	0.14	Non-primate mammal Non-mammal vertebrate Cellular	100	1.0
6. Ape-like	0.16	Ape Ancestor	100	1.0
7. Different	0.06	Different Chimpanzees and humans	100	1.0
8. Non-existent	0.02	Did not exist	100	N.A.

Overall Understanding of how Humans Evolved over Time

There was a myriad of possible answers that students used to describe human evolution from one billion years ago to 50,000 years ago, as categorised in Table 3. Interestingly, the most common type of view held by students was that humans evolved from a primate across one billion years (category 5; 30%), which grossly underestimates the potential of evolutionary change. Another type of common response described how sister species could transmogrify into one another, or across taxa (category 6; 14%). Some responses stated that a microbial organism was the organism that evolved to become human, but with several large gaps in between evolutionary time (category 2; 13%). There were respondents who stated that a non-mammal vertebrate (fish, amphibian or reptile) at one billion years ago evolved to become human (category 3; 9%). Other respondents wrote that human features were conserved over one billion years ago (category 8; 9%) or simply that differences increased back in time (category 9, 9%). Preliminary analysis of the data showed that males and females could be found in each major category. Although males and females were not always evenly distributed for each of the categories, the sample sizes were too small to make meaningful statistical comparisons. Actual samples of students' answers are also provided in Table 4 in order to illustrate the basis for which their answers are classified.

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Table 3
Students' Overall Understanding of How Humans Evolved (n=192)

Category	Weighting	Sub-categories	Consistency of agreement	
			% Agreement	K
(1) Inanimate Object to human	0.01	Originating from a stone Originating from a dust particle	100	1.0
(2) Microbe to human (with significant gaps)	0.13	Originating from a bacteria / prokaryote Originating from a unicellular eukaryote Originating from a multicellular organism	100	1.0
(3) Non-mammal vertebrate to human	0.09	Originating from an aquatic organism Originating from a fish-like organism Originating from an amphibian Originating from a reptile	100	1.0
(4) Mammal to human	0.03	Originating from a non-primate mammal	100	N.A.
(5) Primate to human	0.33	Originating from a monkey or monkey-like organism Originating from an ape or ape-like organism Originating from a chimpanzee Originating from an orangutan	100	1.0
(6) Transmogrificationist	0.14	Indication that species transmogrifies into a sister species Indication that species transmogrify across unrelated organisms	88.9	0.767
(7) Acceptable	0.03	Similar portrayal to timeline that scientists accept	100	N.A.
(8) Human features conserved across time	0.09	Humans did not exist back in time Ancestors back in time were similar to human Minimal changes has occurred	100	1.0
(9) Increase in differences	0.09	Differences increased back in time Similarities decreased back in time	100	1.0
(10) Unclassified	0.06	Vague answers Did not answer the question	100	1.0

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Table 4
Samples of Student Answers for Each Category

Category	50,000 years ago	200,000 years ago	4 million years ago	50 million years ago	1 billion years ago
(1) Inanimate Object to human	cro-magnons	Neanderthals	a small lumpy mass	a little animal cell	a dust particle from outer space
(2) Microbe to human (with significant gaps)	human	Neanderthal-like	like a chimpanzee	reptilian	bacteria
(3) Non-mammal vertebrate to human	hairy caveman	hairy humpback creature	hairy frog	fish with hands and legs	fish
(4) Mammal to human	humans who walk on four	humans with fur	like chimpanzees	like monkeys	like whales
(5) Primate to human	able to walk on two legs	ape	walk on fours	look like monkey	look more like monkey
(6) Transmogrificationist	the same as now	slight hunched	chimpanzee	orangutan	gorilla
	walk like chimpanzee	gorilla	monkey	dinosaur	tortoise
(7) Acceptable	human-like features	ape-like	primate-like	mammal-like	prokaryote-like
(8) Human features conserved across time	humans	humans	humans	humans	humans
(9) Increase in differences	50% human 50% chimp	40% human 40% chimp	30% human 30% chimp	20% human 20% chimp	a completely different thing!
(10) Unclassified	have own uniquely different features	similar to chimpanzees, stands upright	same ancestor	forms distinct arms and legs	similar to other land ancestors

Discussion

Rejection of Evolution Theory

The data informs that many biology students in Singapore do not support the theory of evolution, as well as the reliability of the scientific techniques supporting the theory, such as paleontology. Despite having been taught the topic evolution formally, only 62.6% of the respondents thought that evolution had actually taken place, and only 61.2% trusted the reliability and accuracy of paleontology (refer to table 1). The remaining respondents expressed that they have doubts regarding evolution or paleontology. This data is largely compatible with the finding that 43-47% of adults in America do not believe in evolution (Williams, 2009).

Specifically, in the spaces provided where students were allowed to provide additional explanations, several students declared that evolution is "merely a theory and might not actually have taken place". Others doubted the relative accuracy of paleontology in determining relationships between organisms, and especially since the fossil record is not complete (with transitional forms missing).

Contexts of Student Descriptions about Human Evolution

The use of a free response item had enabled students to freely express how they thought humans evolved. Some contexts highlighted in Nehm and Ha (2011) were probably missing or very low in frequencies because the original context of the question was based on ancestor-descendant relationship, and no future predictions or projections of what humans might be like in future was required.

It is useful to note that while overall, across all time points, students described gain or loss of traits almost equally for how they understand human evolution, the expression of gain or loss of trait is not evenly distributed throughout the evolutionary time frame. When describing a relatively shorter term of evolutionary time for human evolution (for example, from 50,000 years ago to today), students tend to express loss of traits, but when describing a longer term of evolutionary time (from 1 billion years ago), students tend to express gain of traits. The finding has not been reported in the literature as far as is known, and the length of evolutionary time might be a confounding variable that may interfere with studies measuring the frequency of gain or loss of trait (Nehm & Ha, Item feature effects in evolution assessment, 2011). More work is required in order to evaluate the extent in which students adopt trait gain or trait loss positions in free response situations.

The most common category of description was for lineage or taxa. This suggests that when tasked to conceptualise how an ancestral organism looked like, most students would first and foremost attempt to first categorise the mental image based on an existing schema that fits the image. Trait descriptions were considered comparatively low in frequency, and the frequency tends to decrease further back in time. This suggests that students have difficulties speculating the traits that the ancestral organism possesses, relying on lineage/taxa descriptions instead.

The Last Common Ancestor of Chimpanzees and Humans

The fossil records did not always reveal a consistent picture regarding human and ape evolution (Strait & Grine, 2004). Such uncertainties about the precise events, or their underlying causes in human evolution lead to considerable controversies and speculations regarding the precise organism (or group of organism) that might have been the last common ancestor between humans and apes. This might have led to many science curricula omitting human evolution altogether. Also, for curricula that include human evolution, there is a lack of reliable materials for teachers to use, as well as errors in science publications and cartoons (Dougherty, 2011). Nonetheless, the fact that Singaporean students are not taught formally in human evolution is an opportunity to understand the students' raw understanding (as contrasted to facts that they might have committed to memory) about how humans are related to other organisms, and thus establish a measure for how they understand evolution.

Most palaeontologists conclude that humans as a species diverged from another extinct ape-like species some 6 million years ago (Dougherty, 2011), although recent fossil evidence suggests that the last common ancestor might have existed around 4.4 million years ago (White *et al.*, 2009). One commonality remains for the different fossils proposed to belong to the last group of common ancestors shared by humans and other existing apes though: they show very little similarities to any of the extant species of apes present today (Pough *et al.*, 1999). In other words, they were neither similar to chimpanzees nor humans.

An appropriate answer would be an ape-like ancestor, or simply, a (different) species of ape. A non-committal answer, "primate", technically correct to describe the group of animals that the last common ancestor is found in, is imprecise as it would include species of monkeys (mostly tailed forms) as well. Nonetheless, this imprecise and non-committal answer is accepted as students might not have been formally introduced to the topic of primatology in their studies.

Even after this allowance, the analysis of the answers of students regarding the common ancestor at 4 million years ago revealed several surprising results, suggesting how strongly entrenched their ACs in evolutions were. Based on Table 2 alone, the proportion of biology students who can provide scientifically acceptable views of the last common ancestor shared between humans and chimpanzees was seen here to be very low (around 23%). In fact, the dominant views held by most students (31%) was that an extant ape (chimpanzee, orangutan or gorilla) gave rise to humans, or that humans alone (15% of views) or an organism that had a mix of human and chimpanzee characteristics (10% of views), gave rise to the current populations of humans and chimpanzees.

The finding suggests that in this study, many students possess transmogrificationist views that populations might be specifically morphed into a separate species as described by Gregory (2009). Responses that portray the ancestor as a human or hominid (15%) at 4 million years or older probably suggests similar views that humans have remained relatively unchanged over millions of years.

Students' Overall Understanding of Human Evolution

Only 3% of students' answers were able to portray macro-evolution close to the way scientists describe (see category 8 in table 3). This is hardly surprising because the biology syllabus in GCE A' level had not required for students to study macro-evolution from micro-organisms to complex vertebrates. It is possible that the students were not entirely sure of the definition of the terms they used as well, as described by Trowbridge and Mintzes (1988).

Given the insufficient content knowledge that students were exposed to, answers that were able to reasonably capture the general changes across evolutionary time but with incorrect starting points or large gaps were considered acceptable, and in total made up only 36% of the answers of respondents.

In the single category with the largest number of respondents, 29% stated that a primate (inclusive of a named extant ape) was the distant ancestor of humans 1 billion years ago (category 5). Their answers have described very little changes from the ancestral primate at 1 billion years ago to the human species of today. In another category with similar answers (category 9), 6% have insisted that the ancestor of humans at 1 billion years ago is a human, or that human ancestors did not exist at all, indicating the inability to accept that the human species has undergone any substantial changes across evolutionary time. Such a view is consistent with the research findings about another AC that humans and dinosaurs co-existed on earth 65 million years ago, and demonstrates clearly the strong doubt that some students have regarding evolution.

Another category that indicates the presence of a set of obvious student ACs was category 6, in which 17% of students indicated the ability for a differentiated species to transmogrify into another unrelated species, such as from a fish to a turtle to a human, or how a sister species transmogrifies into another sister species, such as from orangutans to chimpanzees. In fact, a closer look at category 5 indicated that approximately half of those responses (n=26) includes the chimpanzee as one of the ancestors of humans, potentially increasing the proportion with transmogrification-based ideas to 30%.

Also, it is very surprising to note that a very small number of students (n=2) found it plausible that dust or stone (inanimate objects) could have been the very distant ancestor of humans, suggesting subscription to the idea of spontaneous generation, long regarded as an obsolete model explaining the origins of life!

Implications for Curriculum, Instruction and Assessment

The greatly diversified views of students regarding human evolution, and the observation that many of them possess notable ACs, are a great cause for concern. The answers of many of the respondents indicate that a significant proportion rejects evolution, doubts the evidence for evolution, or possess ACs about how evolution can lead to different forms of organisms present on earth.

The finding is generally in line with similar research reports of student ACs in evolution employing predominantly multiple choice questions or selected interviews (Geraedts & Boersma, 2006; Clores & Limjap, 2006; Abraham *et al*., 2009; reviewed by Gregory, 2009), and qualitative analysis of large numbers of students' answers based on the grounded theory have further revealed that many students (in fact, the majority) do not understand evolution according to what they have been taught. The ACs of many students, especially those related to transmogrificationist thinking, are especially apparent in this study. The seeming disconnect from scientifically acceptable conceptions and what learners experience in their everyday life (via media and other means) makes it difficult for them to accept or understand evolution, as demonstrated via their descriptions of human evolution. It might be necessary to overcome the two types of ACs (lack of belief versus scientifically inacceptable understanding of evolution) separately, and it appears that there are still too few empirical studies on how to create dissatisfaction with ACs in order to reject them. The robustness of student ACs, as described by Chi (2005), indicates that much more work is required to help learners overcome them, and adopt scientifically supported conceptions.

In order for students to become discontented with their ACs and begin on the journey to change / correct these ACs, it is necessary to re-design how evolution is taught in the classroom. For example, students should be introduced more thoroughly to the taxonomic groupings at the broad level to help them overcome problems with terms used in classification (Trowbridge & Mintzes, 1988). A more constructivist approach might also be in place for students to develop dissatisfaction with their current ACs to begin the journey towards altering misunderstandings and ACs in evolution, based for example on the work by Janssen *et al.* (2009) and Abraham (2009), and also the human and ape evolution example used in this study.

The finding from our work that students might prefer to describe trait losses for short evolutionary timelines (likely for intraspecies differences) should be useful for curriculum design, based on examples such as intraspecies variation, especially since Nehm and Ha (2011) noted that students tended to produce more naïve conceptions when describing trait loss as compared to describing trait gains. However, further work is required to detect how the preferences of learners change when describing evolutionary changes in another organism, or when the assessment item is more structured.

Our study reveals the ubiquity of ACs in evolution, even in Asian countries. The common types of ACs noted in this study are a lack of belief in the validity of evolution, as well as transmogrificationist thinking for how species form. Our qualitative study presents a possible scenario for which biology educators can consider to introduce constructivism into the classroom, in order to understand how students think humans evolved.

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