Japanese College Students' Understanding of Evolution

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INTRODUCTION

A lot of research has investigated students' naive concepts and understanding associated with the physical world (e.g., Brown, 1993; Chi, Feltovich & Glaser, 1981; Clement, 1982; Erickson, 1979; Gunstone & White, 1981; Johsua & Dupin, 1987; McCloskey & Caramazza, & Green, 1980; Piaget, 1970; Trowbridge & McDermott, 1980; Vosniadou & Brewer, 1992). Although less attention has been paid to an understanding of the living world, recent research has clarified various naive concepts and theories of biology (Brumby, 1984). In particular, students' conceptual frameworks about evolution have been investigated by a lot of studies (Demastes, Settlage, & Good, 1995).

These studies consistently document that a majority of students have deeply entrenched naive theories of evolution which are similar to some old evolutionary theories which appeared and were then refuted in the history of evolutionary biology. For example, students understand "adaptation" as an individual organism's conscious and deliberate response to environmental changes and as being caused by some purposeful design (Brumby, 1984; Clough & Wood-Robinson, 1985; Hallden, 1988; Renner, Brumby, & Shepherd, 1981). Anthropomorphism and teleology are commonly seen in students' explanations of evolutionary phenomena (Jungwirth, 1975; Settlage, 1994). Many studies reported that students' view of evolution is similar to a Lamarckian view, (1) in that they place little importance on the role of population variability but regard a species as a homogeneous population (Bishop & Anderson, 1990; Hallden, 1988), (2) in that they do not attribute the origin and survival of new traits in a population to random genetic mutation or sexual recombination and natural selection, but think new traits are produced by an organism's need, use and disuse, and the environmental influence, and that those traits are inheritable (Bishop & Anderson, 1990; Brumby, 1984; Deadman & Kelly, 1978; Jimenez, 1992; Kargbo, Hobbs & Erickson, 1980; Settlage, 1994), and (3) in that students view evolution as a change of traits in all members of a population rather than as a change in the proportion of organisms with specific traits in a population (Bishop & Anderson, 1990; Brumby, 1984; Hallden, 1988). Also, it was reported that students have other types of naive theories which are similar to orthogenesis and theistic evolution (Lawson & Weser, 1990).

The reasons why many studies have been conducted on the understanding of evolutionary theories are (1) that evolution is taught as an important topic in most high school and college biology courses (Bishop & Anderson, 1990; Demastes, Settlage, &

Good, 1995), for it is the basis for understanding all of modern biology, but (2) that many students have insufficient understanding of evolution even after being taught about the subject (e.g., Bishop & Anderson, 1990; Jensen & Finley, 1995; Jimenez, 1992). That is to say, in order to develop effective instructional programs on evolution, it is important that they be created based upon a clarification of students' pre-existing naive theories. However, research on conceptions of evolution has so far been mostly conducted in the United States, and South American and European countries, but has been rarely done in Asian countries. If it is to be done in Asian countries, we may get different findings, because the understanding of evolution may be influenced by cultures and religious beliefs. Thus, it is necessary to conduct a cross-cultural study on the understanding of an important biological theory, evolution.

This study investigated what kinds of naive concepts of evolution college students have in Japan as an Asian country, and how their concepts are different from those of college students in American and European countries.

METHOD

Participants

One hundred and eighty-one undergraduate and graduate students with non biology majors from four universities in Tokyo, Japan, participated in the study. They were pretested in terms of the understanding of evolution, and as a result, it turned out that 121 students already showed a good understanding of Neo-Darwinism, a scientific evolutionary theory, and 60 students possessed naive evolutionary conceptual frameworks other than Neo-Darwinism. This study focused upon and analyzed the 60 students' naive concepts of evolution. The 60 students' background information (e.g., grade, age, gender, GPA, biology classes previously taken in high school and college, how many times evolution was taught in biology classes in high school and college, books or articles on evolution read outside of class, and TV shows, videos or movies on evolution seen outside of class) is shown in Table 1. As for religion, 16 students were Buddhists, 2 were Christians, 3 believed in Shintoism, and the others had no religion.

Material Development

The test questions to measure students' conceptual frameworks about evolution were developed from Bowler (1983)'s five major evolutionary theories which appeared in the history of evolutionary biology. Although some previous studies on the learning of evolution focused upon only two conceptions — the scientific conception (Darwinian conception) and the naive conception (mostly Lamarckian conception) (e.g., Bishop & Anderson, 1990; Brumby, 1984; Demastes, Settlage & Good, 1995; Jensen

Table 1. Descriptive Statistics of Student Characteristics

Characteristic	Measurement scale	M	SD
Grade	1 (Freshman) 2 (Sophomore) 3 (Junior) 4 (Senior) 5 (Master) 6 (Doctoral)	2.96	1.59
Age	18, 19, 20, 21.....	21.73	3.27
Gender	1 (Female), -1 (Male)	.18	1.01
GPA	1 - 4	3.31	.44
Biology classes previously taken			
High school	0, 1, 2, 3...	1.25	.91
College	0, 1, 2, 3...	.55	.78
How many times evolution was taught in biology classes			
High school	0, 1, 2, 3...	.74	.78
College	0, 1, 2, 3...	.37	.84
Books or articles on evolution read outside of class	0, 1, 2, 3...	.46	.51
TV show, videos or movies on evolution seen outside of class	0, 1, 2, 3...	.77	.42

& Finley, 1995; Jimenez, 1992), this study focused upon five conceptual frameworks which correspond to the five theories, because some students may have other naive conceptual frameworks which are similar to the historical evolutionary theories (Lawson & Waser, 1990).

Bowler (1983) described the five major evolutionary theories in the following way.

A. Theistic evolution: Variation was not random, but might be directed toward purposeful ends by the Creator's will.

B. Lamarckism: The characteristics are acquired during the life of the organism and are supposed to be passed on to the offspring. In its most popular form, use-inheritance, Lamarckism allows the cumulative addition of bodily modifications created by a new behavior pattern adopted by the organism.

C. Orthogenesis: Evolution is consistently directed along a single path by forces originating within the organisms themselves. These involuntary trends unfold without reference to the demands of the environment and may even lead to extinction.

D. Saltationism: Evolution proceeds by the sudden appearance of significantly new forms. The mutations occur at random and are non-adaptive. Mutation creates

new populations instantaneously separated from the original.

E. Neo-Darwinism: The preferential survival and reproduction of those individuals born with a slight variation in character conferring some adaptive benefit or some advantage in coping with the demands of the environment. The variations were supposed to be produced by a purely random disturbance of the reproductive system through genetic mutation and recombination.

Some questions were adopted or developed from the ones used in Bishop & Anderson (1990), Brumby (1984), Settlage (1994), Jacobson, Sugimoto and Archodidou (1996), and Ohlsson (1992). Also, biological facts used in the tests were adopted from Bowler (1983) and Mayr (1991). The original questionnaires were pilot-tested and revised based upon the students' responses collected in the pilot test.

Measures

An essay and three multiple-choice questions were posed on a questionnaire to measure students' overall conceptual frameworks about evolution. Different evolutionary cases (Cheetah in the essay and Giraffe, Duck, Kallima butterfly in the multiple-choice questions) were treated. In each multiple-choice question, there were five choices that gave different explanations about the mechanism of a species' evolution, which correspond to five major theories of evolution, namely, Theistic evolution, Lamarckism, Orthogenesis, Saltationism, and Neo-Darwinism. In this paper, however, only the results of the essay problem will be reported.

The essay was an open-end question in which students freely explained about how a species evolved. The essay problem is as follows; "Please answer the following question. Cheetahs, the large African cats, are able to run faster than 60 miles per hour when chasing their prey. Assuming that the ancestors of present day cheetahs could run only 20 miles per hour, please explain how you think today's cheetahs developed the ability to run so fast?" The students' essays were analyzed in terms of which conceptual frameworks they used. Their ways of writing were qualitatively analyzed.

RESULTS

All students but one attempted to answer an essay problem on the evolution of cheetahs. Overall, the students' essays tended to be short and included a variety of non-Neo-Darwinian ideas. Much of the students' explanations was vague and did not contain the mechanism of evolution. Even though some students' frameworks were similar to those of some old evolutionary theory such as Lamarckism and Saltationism, their explanations were imperfect in that they lack some important components of these theories. The evaluation criteria for essays were developed by the following

procedure. First, all essays were read and distinctive and representative explanation frameworks were noted and categorized to make a coding schema. After the coding schema was applied to the data to check whether each essay would fit in a category, the coding schema was re-examined and refined. Finally, the following six conceptual frameworks were set. All essays were blindly evaluated and categorized into the six frameworks by two individuals. The categorizing reliability was .92.

Evolutionary mechanism as a black box: Thirteen out of 60 students (21.67%) did not clearly explain the mechanism of evolution, namely, how an evolutionary change occurred, but just described what kinds of evolutionary change happened to cheetahs. There were three types of explanations found in this category.

The first type is just a brief description of an evolutionary result, namely, a certain change occurred.

> "[Cheetahs] gradually evolved into a species who could run fast."
>
> "The strength of [cheetahs'] muscles and legs developed in the process of evolution."
>
> "Air resistance was reduced by [Cheetahs'] heads becoming smaller and body hair becoming short. The ability to move fast and to sustain power was enhanced by [Cheetahs'] leg-muscles becoming strong. The sole of the paw became strong and solid."

The second is a description of environments and evolutionary changes caused by the environment.

> "In everyday life in which [Cheetahs] chase prey, the abilities for hunting, such as the ability to run fast, were enhanced, and other abilities except for the minimum ones required for sustaining their lives (for example, thick fur and fat to protect the body from low temperature) were gradually lost."

The third type is a description of the corresponding change in environments and traits.

> "I think that cheetahs' prey evolved in the same way as cheetahs. The cheetahs' prey which ran away from the cheetahs developed the ability to run faster and correspondingly cheetahs came to run faster."
>
> "The number of prey decreased because of an environmental change, and it became harder for cheetahs to catch their prey by running at 20 miles per hour. Cheetahs gradually came to run faster and faster, and finally came to run at 60 miles per hour. Genes related to running fast such as the ones for muscle and skeletal structure evolved gradually."

The way these Japanese students explained the changes is just the same as that of some American college students found in Ohlsson (1993)'s research. According to him, "[t]he typical student does not have any conception of the mechanism behind evolutionary change. He or she views adaptation as a primitive process, a black box which needs no explanation....This student simply postulated the relevant morphological changes." He emphasized the difference between scientific discourse and everyday discourse in his explanation of the reason why students do not pay attention to the mechanism. That is to say, ordinary students, who use everyday discourse, are accustomed to reasoning and explaining various kinds of change without knowledge of the mechanism behind the change, and do not find it necessary to think about the mechanism. On the other hand, scientists are concerned with the causal mechanism underlying a change and are eager to explain the internal structure behind the change. In addition, Ohlsson pointed out the students' tendency to explain an evolutionary change by describing the environments which influence it. When people do not know how a particular change occurred, they are likely to describe the conditions under which the change occurred. It is also a common type of explanation used by ordinary people in everyday contexts and is just the same as the findings of this study noted above.

There may be another possible reason for the black-box explanation. Students may have been under pressure to fill in a blank sheet of paper when they were asked to write an essay. They had to write something although they knew almost nothing about evolution. Thus, they might have taken the strategy of rephrasing the content of the essay problem or of describing what easily came to mind, which was eventually some morphological changes or environments related to evolutionary changes.

Teleological evolution: Fourteen students (23.33%) mentioned teleological reasons to explain Cheetahs' evolutionary changes. The typical assumption is that a species changes due to environmental need. Students often use words with teleological meanings such as "need," "necessary," "have to," "in order to," and "because."

> "[Cheetahs] needed to develop the ability to run faster in order to survive in the world where the stronger prey upon the weaker."
>
> "It was necessary for cheetahs to run fast in order to survive as a species, for example, when they were chasing prey or running away from danger. [Cheetahs] gradually came to be able to run fast by necessity in their evolutionary process, and it was inherited by the present day cheetahs."
>
> "Probably the ancestors of cheetahs' prey did not run as fast as the present day prey, and therefore it was easier for cheetahs to catch them. However, the prey gradually evolved into animals who could run faster, and therefore [Cheetahs] could not help developing their muscles in order

to catch their preys."

"[Cheetahs] gradually developed the ability to run fast because cheetahs, who could not sustain the power to run for a long time, had to catch prey in a short time."

The word "adapt" was also used in the teleological explanations.

"[Cheetah] gradually changed their bodies, namely, developed the ability to run fast to adapt to their environments."

"A long time ago, I guess that [cheetahs] used to eat plants. While [cheetahs] were changing from plant-eating animals to flesh-eating animals, the ability to catch prey became necessary [for cheetahs], and [cheetahs] developed the strength in their legs to run instantaneously at 60 miles per hour. Also, as the number and the kinds of prey changed because of a change of climate, [cheetahs] evolved in order to adapt to it."

Previous studies on naive conceptions on evolution reported the same finding, i.e., that students often explain evolutionary phenomena in a teleological way (e.g., Bishop & Anderson, 1990; Settlage, 1994). Many students mention that organisms need to develop new traits in order to survive or that organisms adapt to the environment to survive. When students use the word "adapt," its meaning is "changing in response to the environment," which is different from biologists' usage in evolutionary contexts (Bishop & Anderson, 1990).

We may be able to interpret the teleological explanation in two ways. The first interpretation is that "teleological evolution" is the same as "the evolutionary mechanism as a black box," because "teleological evolution" does not clarify the mechanism of evolution. Indeed, "teleological evolution" may be different from "the evolutionary mechanism as a black box" in that "teleological evolution" lays out more explicitly why a particular evolutionary change occurred by relating the environments to a direction of advantageous change. However, after all, the teleological explanation does not indicate the mechanism of evolutionary change or the actual process of evolution. The second interpretation is that "teleological evolution" is similar to Lamarckism because it may assume organisms' intention to develop new traits in response to the environment. "Teleological evolution," however, does not refer to organisms' effort or behavior as a cause of an evolutionary change as clearly as Lamarckism does. Thus, "teleological evolution" may lie between "the evolutionary mechanism as a black box" and Lamarckism.

Lamarckism: Lamarckism is one of the most common naive conceptual frameworks seen in students' explanations of evolutionary phenomena (Bishop &

Anderson, 1990; Brumby, 1984; Jimenez, 1992; Settlage, 1994; Jacobson, Sugimoto, & Archodidou, 1996). In the analysis of the pretest essay, twelve students' explanations (20%) were found to be similar to the Lamarckian framework. They assumed that the cheetahs' effort or behavior in response to the environment led cheetahs to evolutionary change.

> "Every generation of cheetahs continued to run to catch their prey and the repetition of the activity developed the cheetahs' muscles. The cheetahs' prey also came to run faster in their evolution, and therefore, cheetahs naturally learned how to run faster and effectively, which was then inherited by the next generations."
>
> "Cheetahs needed to run when chasing prey in order to survive, and they developed their running ability by training in chasing prey from childhood and by trial- and- error in hunting prey."
>
> "Cheetahs' prey tried hard to run away in order not to be eaten, and such behavior developed the prey's muscles and ability to run away at more than 20 miles per hour. Cheetahs endeavored to chase prey which ran at more than 20 miles per hour, and they came to run faster through such activity. This incident happened repeatedly, and finally cheetahs came to run at 60 miles per hour."

Although all ten students mentioned cheetahs' effort or activities as the cause of new traits, only two students explicitly described the acquired new traits as being inherited by the next generation. However, most students explained that the evolutionary change gradually occurred across generations, which suggests that they believed in the inheritance of acquired traits from generation to generation. In addition, although they implied that population change is caused by change in each of the individual organisms without paying attention to population variability, they did not clearly explain the notion of a species as a homogeneous population. As a result, these students' explanations can be called "Imperfect Lamarckism."

Selectionism: Fifteen students (25%) referred to natural selection to explain cheetahs' evolution. The students' explanations can be categorized into two types of selectionism; "static selection" and "gradual selection."

"Static selection" is a thorough selection by which all organisms with an advantageous trait survive and produce offspring, whereas all the others without it become extinct. A variation within a species is all or none, and the probability of survival or reproduction is not assumed. "Static selection" may be similar to "Saltationism" in that it presumes the sudden appearance of a distinctive character which instantaneously separates the new population from the original. This naive

concept is also seen in the explanation of American college students (Ohlsson; 1992). Eight students used "static natural selection" in their explanations of the evolution of cheetahs.

> "A mutation caused some cheetahs who had the ability to run faster to appear, and they won in the struggle for existence and survived."
> "Only cheetahs who could run fast survived because they had an advantage when catching prey and reproduced the next generation (their genes were inherited onto the next generation), while other cheetahs who could not run fast died out."

Seven students explained this evolutionary phenomenon through "gradual selection." "Gradual selection," contrary to "static selection," assumes the probability of survival and reproduction as well as the gradual evolutionary change across generations.

> "Some cheetahs who could run faster were likely to catch more prey and survive longer than others who could not. Thus, cheetahs who ran faster passed their genes onto the next generation. On the other hand, cheetahs who could not run fast tended to starve to death and the percentage of these cheetahs gradually decreased. This process was repeated over generations and finally today' s cheetahs came to run at 60 miles per hour."

Although "gradual selection" is most similar to "Neo-Darwinism," only three out of eight "gradual selection" students used the concept of mutation to explain how a new trait originates. None of the other students clarify the mechanism which produces the variability within a species. It was a great problem for Darwin himself to search for a new source of genetic variation. Darwin "believed from the beginning in the overwhelming importance of natural selection as the mechanism responsible for the production of adaptation, but he "desperately needed to find some mechanism that would produce the variation needed for the operation of natural selection" (Mayr, 1991). Thus, it was no wonder that most students had no idea about the origin of a new trait or no consideration of the necessity to explain the mechanism. In addition, most students did not explicitly mention the roles of genes in evolutionary change. As a result, the conceptual framework of the "gradual selection" students can be called "Imperfect Neo-Darwinism."

Combination: Four students (6.7%) explained the cheetahs' evolution by a combination of two different frameworks: Lamarckism and Darwinism.

> "The number of prey, which could be caught by cheetahs who ran at 20 miles per hour, decreased through overhunting or for other reasons. That

> is why [cheetahs] were trying hard to chase new prey. This established the evolutionary direction of cheetahs gradually increasing running speed, and [cheetahs] actually evolved in the accordance with this. Another explanation is as follows: Some cheetahs with an advantageous trait (the ability to run faster) survived and those cheetahs mated to breed children (the gene for this characteristic was inherited onto the next generation). This process occurred repeatedly."
>
> "Some cheetahs, who could run fast, happened to be born with a mutation or genetic recombinations. In addition, some cheetahs came to run fast by always trying to run fast. The genes related to running fast were inherited by the offsprings, and the cheetahs who could run fast had more chance to survive long enough to produce offspring."

These students seem to believe in both the inheritance of acquired traits in Lamarckism and natural selection in Darwinism. However, they seem to harmoniously integrate the ideas from the two different frameworks to reconstruct a new plausible explanation rather than an incoherent explanation.

Teleological change through a mutation: Only one student (1.67%) explained the cheetahs' case through a teleological mutation. He said "A mutation enabled cheetahs to run at more than 20 miles an hour, and through the accumulation of the changes by mutations, they finally came to run at 60 miles per hour." He did not assume that a mutation occurs randomly but believed that a better mutation always happens. Also, natural selection did not come to his mind as a device for selecting variable traits caused by mutation.

DISCUSSION

This study investigated what kinds of naive concepts of evolution Japanese college students have, and whether their concepts are similar to or different from those of American or European college students, and if so, how.

Firstly, it was found that Japanese students have six distinctive naive theoretical frameworks of evolution; "Evolutionary mechanism as a black box" which does not clearly explain the mechanism of evolution, "Teleological evolution" which mentions teleological reasons to explain evolutionary changes, "Lamarckism" which assumes that the organism's effort or behavior in response to the environment leads them to evolutionary change, "Selectionism" which attributes natural selection by which the organisms with an advantageous trait survive and produce offspring to their

evolutionary changes, but does not clarify the mechanism which produce the variability within a species, "Combination" which explains evolutionary change by a combination of two different frameworks such as Lamarckism and Darwinism, and "Teleological change through mutation" which assumes evolutionary change through a teleological mutation.

Secondly, both overlapping features and different features of evolutionary conceptions were found between Japanese students and American or European students. Both Japanese students and American and European students had very similar naive conceptions of evolution, that is, a Lamarckian conception. Also, it was found that the way some Japanese students wrote an essay was just the same as that of some American college students (Ohlsson, 1993). That is to say, both of them just described relevant morphological changes or the conditions which influenced the changes without explaining the mechanism behind the evolutionary changes. However, at the same time, Japanese students were found to be different from American and European people in that few Japanese students believed in creationism or determinism and almost all of them had an understanding of common descent and the multiplication of species. The reason may be that few Japanese students who participated in this study were Christians, and therefore the beliefs of most students were not influenced by religious beliefs specifically related to Christianity.

Another interesting finding from this study is that some students, who used two conceptual frameworks to explain an evolutionary case, seemed not to be confused, although previous research on the learning of evolution considered negatively the parallel use of incompatible frameworks (Jimenez, 1992; Hallden, 1988). Indeed, if students unconsciously use two incompatible frameworks simultaneously to interpret one evolutionary case, their understanding can be naturally interpreted to be chaotic. In this study, however, some students seemed to consciously extract important and useful ideas from two different frameworks and harmoniously integrate them to reconstruct a new plausible explanation rather than an incoherent explanation. Thus, either chaotic thinking or orderly thinking may underlie the apparently similar explanations which consist of two different conceptual frameworks. The difference between chaotic thinking and orderly thinking may be related to the difference in metacognition or analytic ability. Further research on this problem will be necessary.

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