THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Science Education)

DEGREE

Science Education — FIELD

Education — DEPARTMENT

TITLE: Enhancing Thai Students' Scientific Understanding of Evolution: A Social Constructivist Approach

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THESIS

ENHANCING THAI STUDENTS' SCIENTIFIC UNDERSTANDING OF EVOLUTION: A SOCIAL CONSTRUCTIVIST APPROACH

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A Thesis Submitted in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy (Science Education)

Graduate School, Kasetsart University

2006

ISBN 974-16-1491-8

Pongprapan Pongsophon 2006: Enhancing Thai Students' Scientific Understanding of Evolution: A Social Constructivist Approach. Doctor of Philosophy (Science Education), Major Field: Science Education, Department of Education. Thesis Advisor: Professor Vantipa Roadrangka, Ph.D., Ed.D. 334 pages.
ISBN 974-16-1491-8

This interpretive research aims to study 1) Thai students' understanding of evolution, 2) the existing situation of teaching and learning evolution, 3) to propose an alternative way of teaching and learning evolution to promote the scientific understanding of evolution and 4) study the effect of the intervention on students understanding. The research is divided into 3 phases; Exploratory Phase (academic year 2003), Intervention Design and Development Phase, and Intervention Implementation and Evaluation (academic year 2004). In the first phase of study, 253 Grade 12 students from 3 schools in Bangkok and Nontaburi had their understanding of evolution assessed by the Evolution Diagnostic Test (EDT) and Evolution Fundamental Concept Test (EFCT) and their opinion of the existing situation in teaching and learning evolution by the Current Situation of Teaching Evolution (CSTE) in terms of teaching methods, instructional materials and media, assessment, learning resources. The three teachers of these students were also interviewed in-depth on the same issues. The findings of this phase were taken into consideration in the design and development of Evolution Learning Unit (ELU) in the second phase. ELU is based on social constructivism. The intervention was introduced with 270 Grade 12 students in the same three schools as in the first phase and the same teachers in academic year 2004. A multi-site case study was conducted in the three settings to study how the teachers employed the unit and the effect of the intervention on the students understanding of evolution by a number of data generation techniques; interviewing, classroom observation, document analysis and testing.

The findings from the first phase indicated that Thai students used non-scientific models to explain evolutionary concepts even after the instruction. They did not have a sound understanding of the fundamental concepts of evolution. For a particular context and concept, the student preferred one model to the others. The students tended to apply the same models to similar contexts and related evolutionary concepts. The choice of model was influenced by their personal world views; anthropomorphism and teleology, the instruction and textbook. As for the situation of teaching and learning evolution, the method of teaching evolution was not aligned with National Science Curriculum Standards (IPST, 2002). Teachers instructed the students rather than letting them construct the knowledge on their own. Teaching focused on facts and memorization rather than understanding. The findings of the third phase of study indicated that different teachers employed ELU differently. This had an effect on student learning. Teachers' content knowledge and beliefs on effective teaching and learning were found to be determining factors of intervention implementation. The social interaction, the key strategies of ELU could enhance students' scientific understanding of the role of variation, changes in a trait, and speciation. The students, however, still applied non-scientific models to explain the origin of variation and speciation. The understanding of origin of variation was resistant to instruction but for speciation, the instruction may have had an effect on the students understanding of this concept.

Student's signature

Thesis Advisor's signature

25 / 04 / 2006

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to Prof. Dr. Vantipa Roadrangka, the chairman of the doctoral committee for dedicating countless hours reviewing every single line of my dissertation, discussing ideas, suggesting, encouraging, and guiding me through many of the rough spots I have encountered throughout the study at Kasetsart University. I am also indebted to my dissertation committee members, Prof. Dr. Alister Jones, Asst Prof. Dr. Naruemon Yutakom, Associate Prof. Dr. Pattanee Jantrarotai and, of course, Dr. Alison Campbell for their guidance, mentorship and continuous support.

Furthermore, I cannot thank the teachers and their lovely students of this study enough for their participation; sharing their thoughts and time with me. I wish to express appreciation to Mr. Malcolm Bray, the scientific consultant of National Science Museum for all his time reading and editing this thesis.

I wish to extend my deepest gratefulness to my family members who provided me their seemingly tireless support and encouragement. My thanks to them cannot be fully articulated in words.

I extend many thanks to the Institute for Promoting Teaching Science Technology for the scholarship to study in a doctoral level in science education at Kasetsart University and their financial support for attending NARST conference 2006 at San Francisco and the Graduate School, Kasetsart University for the research fund.

Pongprapan Pongsophon
March 2006

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CHAPTER I

INTRODUCTION

Background of the Study

> …Internationally, societies are changing from industrial to information-based societies in which the creation and dissemination of knowledge play critical roles in both individual and social development. Accordingly, an education paradigm for knowledge-based societies is emerging in which high-order thinking skills, communication skills and continuous learning are emphasized. (Atagi, 2002: 2)

Nationally, educators, politicians, and bureaucrats, all agree that the reform of education is a need for Thailand. Thailand's international competitiveness has declined in recent years, in large part, due to weak human resources, especially in the science and technology fields (Office of the National Education Commission, 1999a). The Third International Mathematics and Science Study (TIMSS), cross-country data survey and study, was carried out in 1994-95 in 41 countries around the world. The comparison between student achievement in maths and science was aimed at showing where several countries stand in terms of maths and science education. Compared with the international average, Thai student achievement in maths and science especially at grade 4 and 8 falls behind, and is in the bottom five countries (Poshyananda, 2000). Consequently, The Eighth National Education Development Plan for 1997-2001 (National Economic and Social Development Board, 1997) raises the issues of inadequate analytical thinking, creativity, problem-solving as well as basic knowledge and application of mathematics and science. Classic factors contributing to poor quality of mathematics, science and technology education have been identified. The content has been heavily focused on theories – both science and math for their own sake; teaching styles and curricula have been dominated by teacher-centered and the quality of teachers, particularly in rural areas, has been low.

The National Education Act 1999 (ONEC, 1999b) was written in order to move towards education reform in Thailand. The main themes of the Act are twelve years basic education; nine years compulsory education; the decentralization of the administrative systems; the restructuring of the curriculum by giving emphasis to English-language teaching and more focus on the sciences; and, above all, shifting the emphasis from teaching to learning (ONEC, 1999). Learning reform is the heart of the Act: the teachers are asked to encourage students to display more individualism and initiative and end parrot-fashion rote learning, with no room for thinking. As stated in the Act, curriculum and educational programs in all subjects should create a happy learning environment; support higher order thinking; and encourage the learners to learn more from nature and the environment (ONEC, 1999). Consequently, The Institute for the Promotion of Teaching Science and Technology (IPST), a state enterprise responsible for the promotion of teaching and learning science in Thailand, launched the National Science Curriculum Standards (IPST, 2002) to trigger a revolution in science education nationwide. The standards have resulted in rethinking about science teaching; professional development for science teachers; assessment of science education; science content; science education programs and science education systems (Bhasomsap, 2003).

Guided by the standards, all schools throughout the country have to develop their own curriculum, beginning in 2004 (Ministry of Education, 2002). It has become more flexible for the schools to select learning resources and instructional materials, organize their content and time, and design learning activities to enhance student learning based on classroom context, student need, culture, local wisdom and learning resources. The schools had to start implementing the new school science program 2003 in grades 1, 4, 7 and 10. The implementation would be extended to other grade levels in the following years. By the year 2005, the school based curriculum had to be employed in all grade levels. However, the schools had depended on IPST materials; teacher manuals, textbooks, and instructional materials for a long time. Developing a school science program on their own, therefore, is a new difficult job for many schools (Bhasomsap, 2003 and Luangmaneewach, 2002).

They need a lot of support from everyone concerned; policy makers, parents, the school district, the principal, and science education researchers.

This study was conducted in response to the educational reform. It aims to improve teaching and learning science by developing a learning unit based on the National Science Curriculum Standards to enhance students scientific understanding of science concepts. In this unit, the students will be given ample opportunities to use a hands-on approach in learning and to work individually as well as cooperatively with others. The study also aims to give the teacher's ideas how to develop a school science program. The process of design, development and implementation of the science program in this study would be useful for other teachers or curriculum developers who are developing a school science program.

Significance of the Study

Evolution underpins all of modern biology (Dobzansky, 1973; Mayr, 1982; AAAS, 1993; NRC, 1995; and NSTA, 2003). Theories of biological evolution set out to explain diversity amongst organisms, the origin and history of that diversity and the natural process by which the diversity has developed and by which the variety is sustained (Skelton, 1993; Strickberger, 1996; Freeman and Herron, 1998; and Futuyma, 1998). Evolution helps students understand the world (Freeman and Herron, 1998) and science better (National Academy of Sciences, 1998; Rudolph and Stewart, 1998). It deals with the questions as how come there are such a great number of living things on earth today, what human being came from, how the universe is originated. To answer these questions, students have to associate various fields of science such as genetics, ecology, taxonomy, geology, molecular biology, astronomy etc, to reconstruct history of life. The students could also apply the understanding of evolution to explain daily life situations; agricultural and medical problems (Freeman and Herron, 1998). An example of this would be why a number of mosquito populations are today resistant to DDT, even though those species were not resistant to DDT when it was first introduced? Why have promising AIDS treatments, like the drug AZT, proven ineffective in the long run? In addition, evolution helps students view science as an integrated discipline and not a fragmented one (National Academy of Sciences, 1998; Rudolph and Stewart, 1998; Passmore and Stewart, 2002). Evolution reflects the development of scientific thoughts and depicts science as a dynamic field of inquiry.

The significance of evolution is acknowledged in national (IPST, 2002) and international science education standards (AAAS, 1993; NRC, 1995; Ministry of Education of New Zealand, 1993). It is a unifying theme of school science program. In addition, evolution has become an issue in science education research (Rudolph and Stewart, 1998). There was a launching of special issues on this area by a number of professional journals, and many conferences and seminars on evolution education over the last decade. Some examples are the special issue on evolutionary biology education by the Journal of Research in Science Teaching in May 1994, the Proceedings of the 1992 Evolution Education Research Conference at Louisiana State University, the Public Lecture Series 2001-2002 held by Dialogue on Science, Ethic, and Religion of the American Association for Advancement of Science. All of these prove the importance of evolutionary biology in the society and in the science education community. According to National Science Curriculum Standards (IPST, 2002), the content of evolution was stated in sub-strand 2: Living Things and Life Processes strand, Standard Science 1.2.as "a school-based curriculum should give students opportunity to seek for information, discuss and explain the process of habitability, genetic variation, mutation, the production of biodiversity, and construct a model to explain evolutionary phenomena: the effect of environmental change on the survival of living things and biodiversity…" (IPST, 2002: 16). From the standards, the students should understand the interrelationship between genetics, evolution, and biodiversity. They should be able to construct explanatory models to explain evolutionary phenomena.

From previous studies, for a noteworthy number of students, evolution seems to be very difficult to understand especially in the topics of theories of evolution and evolutionary process (Passmore and Stewart, 2002). The alternative conceptions were common even among the highly educated, including medical students (Brumby, 1984). The report of alternative conceptions regarding these topics is continually extended in literature. The previous studies indicate that the majority of students explain evolutionary phenomena by Creationism (Bloom, 1989; Dagher and BouJaoude, 1997; Dowie and Barron, 2000; Woods and Scharmann, 2001) and Lamarckism (Deadman and Kelly, 1978; Brumby, 1984; Clough and Robinson, 1985; Bloom, 1989; Bishop and Anderson, 1990: Greene, 1990; Settlage, 1994; Bizzo, 1994; Robinson, 1994; Anderson, et al 2002; Passmore and Stewart, 2002). The literature also indicates that students are confused with many terms in evolutionary biology such evolution, adaptation, population and fitness. Although these terms are often in everyday use, this usage differs greatly from that in evolutionary contexts (Bishop and Anderson, 1990). These ideas are self – constructed, persistent, and highly resistant to instruction (Anderson et al., 2002). The factors influence these non-scientific views are personal worldviews, religious and local beliefs, cognitive development, and background of genetics knowledge, language, and textbook (Driver, 1985: Bloom, 1989; Tamir and Zohar, 1991; Robinson, 1994; Anderson et al., 2002).

Although a number of studies has been carried out to explore students understanding of evolution, there has been no research done to investigate the issues and existing situation of teaching and learning evolution in Thailand. This study, therefore, aims to fill this gap by studying Thai students understanding of evolution and the existing situation of teaching and learning evolution in Thailand also to propose an intervention to promote a scientific understanding of evolution that is based on the National Science Curriculum Standards (IPST, 2002).

Research Purposes

In response to the National Education Act (1999) and the growing interest in the research on ‘evolution education’ internationally, this study aims to explore Thai students’ understanding of evolution, the existing situation in teaching and learning evolution and develop an intervention aligned with the standards required to promote scientific understanding of evolution. Regarding the intervention design, the researcher intends to create a learning unit that has a practical value in the Thai classroom context. The student understanding of evolution, Thai classroom environment, school philosophy, student background, and IPST guidelines (IPST, 2002), therefore, are taken into consideration in the process of intervention design and implementation.

Research Questions

The research answered the following questions:

1. How do Thai students understand evolution?
2. What is the existing situation of teaching and learning about evolution in Thailand?
3. How do biology teachers employ the Evolution Learning Unit, the intervention?
4. Does the Evolution Learning Unit enhance students scientific understanding of evolution?

Anticipated Outcomes

1. The research profiles how Thai students understand evolution. There has been no research done in this area previously in Thailand, so the findings will form a data base for curriculum developers, teachers, policy makers or other researchers who would like to extend research in this area in the future.

2. This research is useful for other biology teachers who teach evolution. The teachers may adopt or adapt the test items, probing techniques and teaching strategies in this study with their students. This research is not only applicable to teaching and learning evolution, but it could also be applied to the teaching and learning of all branches of science with the development of scientific thought and historical components such genetics, astronomy, physics, chemistry etc.

3. The process of learning unit construction is a concrete example for the teachers in translating National Science Education Standards into a school science program. It is the first time for all teachers in this country to be given an opportunity to develop their own school science program before they have entirely depended on IPST for a long time. This study may give an idea how to deal with the change in a practical way.

Delimitation of Research

This study was conducted with Grade 12 students and 4 biology teachers from 3 schools in Bangkok and Nontaburi in Thailand. By the time this study was carried out, in 2003-2004, all schools still used the former curriculum but was going to implement a school based curriculum in the following year. All teachers were developing a new curriculum and materials or adapting the former curriculum to be aligned with the National Education Act in 1999 and National Science Curriculum Standards (2002). This research aims to investigate and improve student understanding of the evolutionary processes of micro- and macroevolutionary changes. Microevolution and macroevolution are different things, but they involve mostly the same processes. Microevolution is the change of allele frequencies due to processes such as selection, mutation, genetic drift, or even migration) within a population. Macroevolution is evolutionary change at the species level or higher, that is, the formation of new species, new genera, and so forth.

Definition of Terms

1. The Evolution Learning Unit is an instructional unit for evolution which can be used as a whole course or a part of a biology course in a school science program. The unit aims to promote the scientific understanding of evolution. The activity is based on a social constructivist view of learning. The activity focuses on the students' prior conception for individuals find meaning not only through unique experiences but also through social interaction. In the activities of the unit, meanings are shaped through discussion and negotiation between peers and between pupils and

teachers. The unit has involved the use of a wide range of strategies giving students opportunities to try out, construct and apply their understanding of evolution in a range of ways.

2. The existing situation of teaching and learning evolution means the circumstance of teaching and learning evolution in Thailand in academic year 2003 including curriculum, textbook, teaching strategies, instructional materials, assessment, and learning resources.

3. The students understanding of evolution is the students' ideas on the concept of evolution that can be measured by testing and interviewing. When the students are aroused by a number of questions based on evolutionary situations and they choose or give the explanation that corresponds with their ideas. Their answers that are acceptable to a community of scientists are called scientific understanding or a scientific model. The unacceptable ones are called non-scientific understanding or non-scientific model.

Summary and Preview

This chapter discusses the background and significance of the study, its significance in the field of science education, and the research questions raised accordingly. This study aims to examine Thai students understanding of evolution, the existing teaching and learning evolution in Thailand and develop an intervention to promote scientific understanding of evolution that is aligned with the National Science Curriculum Standards (2002) and suitable for Thai classroom contexts. In doing so, four research questions are then considered. The first two research questions which deal with Thai students understanding of evolution and the existing situation of teaching and learning evolution are explored. The findings are used for designing and developing the intervention. The last two research questions ask for the employment of the intervention in Thai classroom settings as well as its effect on student learning. These works will be presented in details in the following chapters which can be previewed below.

Chapter 2 provides a review of a concept of evolution, describes evolution education in Thailand and discusses previous studies on students understanding of evolution and teaching and learning of evolution. The perspectives of learning science are discussed; behaviorism, personal constructivism, social constructivism and the socio-cultural perspective of learning. The chapter makes an argument that learning science is an intentional, social, contextualized activity. Based on previous studies, teaching and learning evolution for comprehension should take account of the social aspect of learning.

In chapter 3, naturalistic paradigm and interpretive research, the philosophical underpinning and research methodology of this the study, are reviewed. The researcher then introduces the research framework. Several data generation methods such as testing, interviewing, classroom observation, and the instruments in terms of the structure and the development process are discussed as well as the analysis. At the end of the chapter is discusses the ethical concern and the strategies for increasing the trustworthiness of the study.

Chapter 4 describes the findings of the survey on Thai students understanding of evolution and existing situation of evolution teaching done in 2003. Students' conceptual difficulties of evolution are discussed and the use of a model of students across various evolutionary contexts and concepts. As for the situation of teaching and learning evolution, the chapter describes the use of curriculum, textbook, teaching methods, and assessment techniques in teaching evolution, problems of teaching and learning, and discusses how the teachers prepared themselves for developing and implementing the school based curriculum. At the end of this chapter, the implication of survey results for intervention design is discussed.

Chapter 5 discusses the design and development of the Evolution Learning Unit (ELU). The chapter starts with a number of guiding principles that ELU is based on. The process of intervention design and development is discussed. The process comprises need assessment, planning session with an advisory committee, developing intervention material, pilot delivery and revision. The chapter next focuses on the content and organization of intervention followed by the comparison with those of the former curriculum. The rational for selecting and organizing content of the ELU are provided. At the end of the chapter, the content and the activity of each lesson are elaborated.

Chapter 6 discusses the implementation and evaluation of the Evolution Learning Unit (ELU). The chapter starts with an initial workshop held before the introduction to train the teachers to use ELU materials and gather their comments on the materials for improvement and teacher support meetings which are held weekly during the implementation to give continuous support for the teachers. The chapter introduces four case studies of the implementation in the second semester of the academic year 2004. In each case, teacher profiles, school and classroom environments, and the nature of the students are described. The last two research questions are posed and investigated in each case. The findings on how the teachers implemented the intervention in their own setting and how this affected the students understanding of evolution are discussed.

Chapter 7 centers on the conclusions of the findings of previous chapters and the implication of such findings to the science education community. Research outlines and research questions are reviewed. The conclusion and implication of findings of each research question are then discussed. At the end of the chapter, suggestions for future work are discussed.

CHAPTER II

LITERATURE REVIEW

Introduction

This chapter reviews some important ideas for teaching and learning evolution. The chapter has five sections. The first section, Concept of Evolution, is the introduction to the discipline of evolutionary biology and its key concepts used in this study. The second section, Evolution Education in Thailand, describes evolution education in Thailand before and during the period of educational reform. The third section, Previous Research on Student Understanding of Evolution, discusses conceptual difficulties in understanding evolution; models of evolution, fundamental concepts of evolution, and the evolutionary process. This section also discusses the encompassing factors of understanding and acceptance of evolution. The forth section is devoted to Theoretical Perspectives of Learning. This section presents the development of perspectives of learning science; behaviourism, personal constructivism, social constructivism and the socio- cultural perspective of learning, and discusses how such developments affect the trend of research in science education. In the last section, Previous Research on Teaching Evolution, there is a review on teaching strategies for evolution; models of evolution and evolutionary process. From the synthesis, the researcher argues that learning science is intentional, social, contextualized activity and social interaction could enhance scientific understanding of evolution. Social constructivism is the theoretical position of this study.

Concept of Evolution

Evolution is a discipline of biological science which discusses the discovery of the history of life, the causes of diversity and the characteristics of organisms (Skelton, 1993). Evolutionary phenomena can be categorized into 2 levels; microevolution and macroevolution (Skelton, 1993; Strickberger, 1996; Freeman and

Herron, 1998; Futuyma, 1998). Microevolution refers to any evolutionary change below the level of species, and refers to changes in the frequency within a population or a species of its alleles (alternative genes) and their effects on the form, or phenotype, of organisms that make up that population or species (Freeman and Herron, 1998). Macroevolution is used to refer to any evolutionary change at or above the level of species. It means the splitting of a species into two or more (speciation, or cladogenesis, from the Greek meaning "the origin of a branch") or the change of a species over time into another (anagenesis).

Darwin, who is nowadays considered as the father of evolutionary biology (Skelton, 1993; Strickberger, 1996), proposed a model to explain the mechanism of the evolutionary phenomena, known as natural selection in his publication, *The Origin of Species* in 1859. The process of natural selection starts with the origin of hereditary variation by mutation and recombination. In his time, Darwin could not explain these causes of variation. Darwin explained that, in a particular environment, only individuals with favourable traits could successfully reproduce and pass on their traits to offspring. Working on genetic variation, natural selection causes changes in the proportions of variants within populations over time leading to adaptation. Natural selection works only on the variation within in a population in an existing environment. It leads to adaptation to current environment, not for the future. Nowadays, the model of natural selection or Darwinism is widely accepted in a community of science and science education because it is well supported by a great amount of evidence (Anderson et al., 2002). In 1930s and 1940s, the model of natural selection was reconciled with the facts of genetics and complemented from the contributions of geneticists, systematists, and paleontologists. Darwinism, at that stage, so called modern synthesis or Neo-Darwinism. In a recent definition, evolution is seen as the change in the genetic structure of populations over time. The process of natural selection is illustrated in figure 2.1.

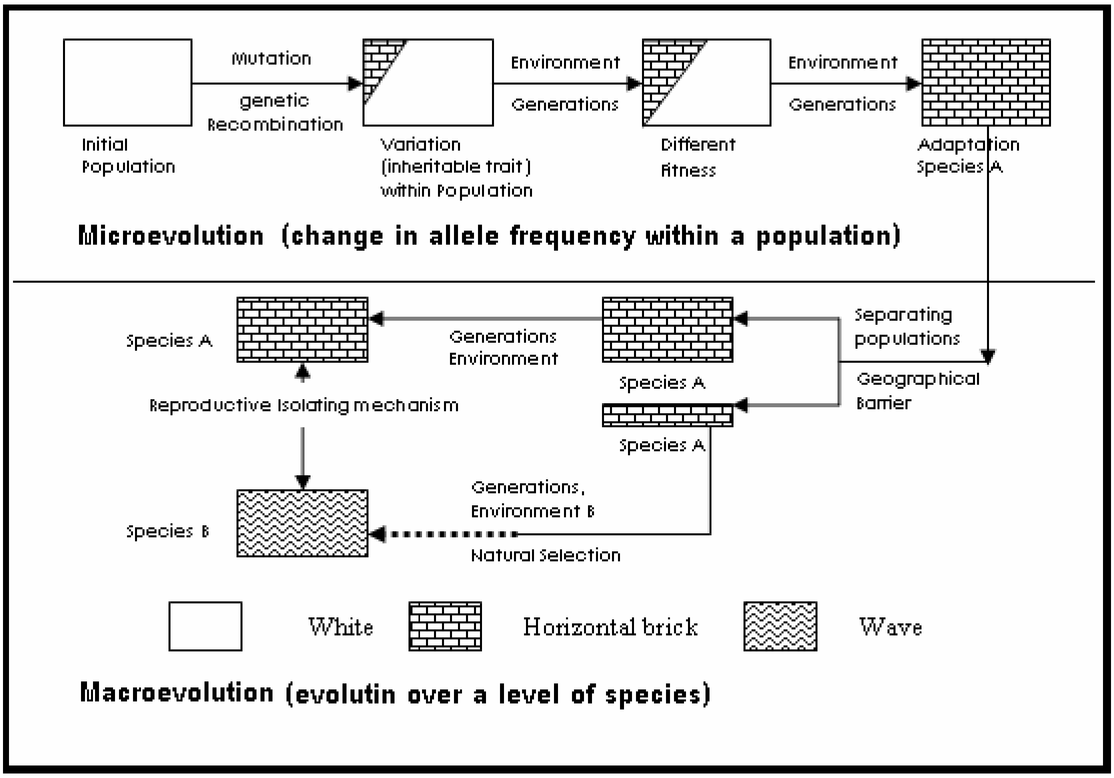


Figure 2.1 Evolutionary Process

Organisms within a species differ from one another in inherited traits, “white” and “horizontal brick”. The genetic variations arise through mutation and genetic recombination (origin of variation). Among these organisms, those best suited to the environment, the “horizontal brick” ones; tend to be most successful in producing young (role of variation). This process is called differential reproductive success. Offspring that are less well-suited to the environment are less likely to survive and less likely to produce offspring. Through differential reproductive success, the frequency of different genetic types in the population changes with each succeeding generation (Change in a trait). Populations change through the change in the frequencies of genetics types in the population, not through the change in individual organisms. Natural selection is directed, determined by the characteristics of the particular environment (role of environment) as shown in the small box in the figure. The population gradually becomes better suited to the environment through the propagation of more fit individuals. All individuals in the population have the "horizontal brick pattern". This process is microevolution. When two populations of a single species are separated for an extended time by geographical, seasonal, behavioural or other barriers, the populations may diverge to the extent that they become separate species (speciation). In the figure 2.1, some of the "horizontal brick" are diverse to those with "wave" patterns. In general, members of different populations are not able to mate and reproduce with one another, although this is not always true in closely related species. Evolution at this level is called macroevolution. From figure 2.1, the process of natural selection comprises five components as follow (Brumby, 1984; Bishop and Anderson, 1990; Greene, 1990 and Anderson et al, 2002).

1. *Origin of variation*: there is the appearance of the genetic variation of inherited traits within a population. The variation is caused by random mutation and genetic recombination

2. *Role of variation*: the variation may produce beneficial, neutral or harmful trait in a population in a particular environment.

3. *Change in a trait*: among the offspring, those having most favourable trait to a particular environment tend to be most successful in producing young while the ones less well-suited are less likely to survive and less likely to produce offspring. The proportion of individuals holding a particular trait changes not the quality of the trait.

4. *Role of environment*: environment is a selecting agent not the quality of a trait.

5. *Speciation*: natural selection causes two genetically isolated populations accumulate genetic differences so they become two distinct species.

However, the model of natural selection (Darwinism) was a topic of debate in Darwin's period because it contradicted with Creationism and Lamarckism, the two current powerful models of explanation (Skelton, 1993; Strickberger, 1996; and Freeman and Herron, 1998). At that time, Platonic and Aristotelian philosophy and Christian theology, known as Creationism, were strongly influential to people's belief. It explains that the earth was a few thousand years old or called a Young Earth. The earth and all living things was created at once and equipped with adaptations by God, the intelligent designer. The earth and living things are unchanging. All living things was organized, according to a divine plan, into a Great Chain of Being in which the organisms were placed and ordered in progression from most imperfect to most perfect.

Lamarckism was another leading explanatory model of origin of species (Skelton, 1993; Strickberger, 1996; and Freeman and Herron, 1998). It was proposed by Lamarck in 1809 in his book *Philosophie Zoologique*. He agreed with the Great Chain of Being but explained its formation differently from Creationism. He thought that all species evolved in progression to establish the chain. The top of the chain is the oldest and most complicated form of life, while the bottom of the chain represents the youngest and simplest form of living things. Lamarck explained that the change of species deviate from a single linear chain by adaptation. The organisms respond to a particular environment by overusing or under using a particular organ which enlarges or deteriorates gradually during their lifespan (Law of Use and Disuse). They can pass this acquired characteristic to the offspring (Law of the Inheritance of Acquired Characteristics).

Evolution Education in Thailand

Before 2000

From 1981 to 2000, high school science in Thailand was oriented by Upper Secondary Education Curriculum (1981, revised in 1990). The content of science was organized into three structures: Structure One was for students who studied the fundamental science course; physical and biological science, and Structures Two and Three for students who studied advance science courses; physics, chemistry, and biology. The Structure One was offered to the students in Art and Humanity and Vocational study programs. The Structures Two and Three were offered for students in Science and Mathematics Programs. The Structure Two took 6 semesters to finish all courses while the Structure Three was designed for students who wanted to finish high school in 5 semesters. The Structure Three was developed by IPST in response to the new entrance examination system in 1997 - 2001 that was held twice a year; before and after the second semester of Grade 12. The Structure Three allow students to take entrance examination twice. The content of biology of the two structures was the same but that of Structure Three was reorganized to be more coherent and integrated (Table 2.1). The content of biology of structure two was fragmented as shown in the textbook. Evolution and its related topics were separated into different grade levels: biodiversity in Grade 10, cell division in Grade 11, and genetics and Evolution in Grade 12. This is contrary to the Structure Three case where students studied all these topics in grade 10: in the first semester of grade 10, students studied cell division; in the second semester, they first studied genetics, then evolution, and biodiversity. By this organization, evolutionary related concepts were connected. Under this new organization, the students learned all fundamental concepts of evolution before studying evolution. They would also be encouraged to apply evolutionary principle to explain the biodiversity of life in the following unit.

Table 2.1 Topics of Biology and Their Sequence between Structure Two and Three in IPST Textbooks of Upper Secondary Education Curriculum (1981, revised in 1990).

Structure 2	**Structure 3**
Grade 10 first Semester (Bio 441)	*Grade 10 first Semester (Bio 442)*
Unit 1: How to Study Biology	Unit 1: How to Study Biology
Unit 2: Living things and Environment	Unit 2: Cell
Unit 3: Biodiversity	Unit 3: Chemistry in Living Things
Unit 4: Cell	Unit 4: Cell Transportation
	Unit 5: Growth and Cell Division
Grade 10 Second Semester (Bio 041)	*Grade 10 Second Semester (Bio 048)*
Unit 1: Nutrients and Survival	Unit 1: Genetics
Unit 2: Digestive System	Unit 2: Evolution
Unit 3: Transportation	Unit 2: Biodiversity
Unit 4: Homeostasis	
Grade 11 First Semester (Bio 042)	*Grade 11 First Semester (Bio 049)*
Unit 1: Energy in Living things	Unit 1: Structures and Functions in Flowering Plants
Unit 2: Respiration	Unit 2: Photosynthesis
Unit 3: Photosynthesis	Unit 3: Gas Exchange, Transpiration and Transportation
	Unit 4: Flowering Plant Reproduction
	Unit 5: Response in Plants
Grade 11 Second Semester (Bio 043)	*Grade 11 Second Semester (Bio 0410)*
Unit 1: Reproduction	Unit 1: Digestive System
Unit 2: Plant Growth	Unit 2: Circulatory System
	Unit 3: Respiration
	Unit 4: Excretory System and Homeostasis
Grade 12 Second Semester (Bio 045)	
Unit 1: Genetics	
Unit 2: Evolution	

Table 2.1 (Cont'd)

Structure 2	Structure 3
Grade 12 First Semester (Bio 044)	*Grade 12 First Semester (Bio 0411)*
Unit 1: Neural System and Sensory Organs	Unit 1: Animal Growth and Reproduction
Unit 2: Hormone	Unit 2: Skeletal System
Unit 3: Locomotion	Unit 3: Neural system and Sensory Organs
Unit 4r: Behaviour	Unit 4: Hormone
	Unit 5: Behaviour
Grade 12 Second Semester (Bio 045)	
Unit 1: Genetics	
Unit 2: Evolution	

In both structures, IPST textbooks suggest guidelines for teaching evolutionary concepts. For instance, evolutionary process by non-random mating, chance, gene flow, mutation, and selection are explained through several cases of evolving organisms: mutation by the effects of gamma-ray radiation treatment on rice strain improvement; natural selection by industrial melanism in peppered moths (*Biston betularia*). To illustrate the mechanism of genetic drift, the textbook draws an analogy between randomly picking up colour buttons from a box and random fluctuations in the frequencies of two or more alleles or genotypes within a population. Most questions arising throughout the textbook ask for interpreting and understanding of the concepts rather than recalling for example; what does it mean by environment as selecting agents? How do mutation and gene recombination cause genetic variation? How does migration produce changes in gene frequencies? However, there is no hands on/minds on activity suggested in the textbook; all conclusions are already presented in the textbooks.

Beyond 2001

According to Basic Education Curriculum (2001), the new national curriculum framework, all schools in Thailand have to develop a school based curriculum. This document was launched in response to educational reform in Thailand, the key message of the National Education Act (1999). The curriculum opens an opportunity for schools to develop their own curriculum. It has become more flexible for the schools to select textbooks and instructional materials, organize the content and time, and design learning activities to enhance student learning based on classroom context, student need, culture, local wisdom and learning resources. Basic Education Curriculum (2001) provides the goals of basic education of the country, scope of all subject areas (strands) and guidelines for developing school based curriculum. According to this curriculum framework, the schools started implementing the new curriculum in 2003 in grade1, 4, 7 and 10. The implementation would be extended to other grade levels in the following years. By the year 2005, the school based curriculum had to be introduced at all grade levels. As for the area of science, the Institute for Promoting Teaching Science and Technology (IPST) launched National Science Curriculum Standards (2002) to be a practical guide for developing school science programs. In addition, this document reviews theories of learning and encourages the curriculum developer to design their intervention based on constructivism. The curriculum standards list a variety of constructivist teaching methods and assessment techniques as well as some useful learning resources such as textbook, URL, and learning centres. This document outlines what students should know, comprehend, and be able to do in the natural sciences over the course of K-12 education. The content of science are organized into eight sub-strands:

Sub-strand 1: Living Things and Living Processes
Sub-strand 2: Life and Environment
Sub-strand 3: Matters and Properties
Sub-strand 4: Forces and Motion
Sub-strand 5: Energy
Sub-strand 6: Processes that Shape the Earth

Sub-strand 7: Astronomy and Space

Sub-strand 8: Nature of Science and Technology

Biology resolves around sub-strand 1 and 2. The evolution was discussed in sub-strand 2 in Standard Science 1.2., that the students should understand the interrelationship between genetics, evolution, and biodiversity. They should explain models of evolution and apply it to explain various evolutionary phenomena.

Previous Researches on Student Understanding of Evolution

Students do have their own ideas about natural phenomena before they move toward school science (Driver et al., 1985, Tobin, 1990; Bell, 1993; Hodson and Hodson, 1998). These ideas, which seem incoherent from the scientists' point of view, are self-constructed and persistent. Even after being taught and challenged by counter evidence, the students have not modified their prior knowledge. They carried scientific ideas with one hand and prior ideas with the other and interchangeably use both of them depending on context (Driver et al., 1985). On the content of evolution, likewise, a significant number of studies reveal that students have difficulty in understanding this unifying concept in a number of ways. This section discuss three areas of difficulty in understanding evolution ranging from the use of models of evolution which are nowadays unacceptable by most practising biologists; common misunderstanding of evolutionary process and the fundamental concepts of evolution. The factors constituting such students' understanding and the expansion on Buddhism and animism, the two major beliefs of Thai people on the natural phenomena, will be encompassed at the end of this section.

Students' world view

From the synthesis of research on student conception of science concepts, Driver et al.(1985) draw out the general features of children's conceptions. These encompass the tendency for students initially to base their reasoning on observable features; the tendency to consider only limited aspects of particular perceptual physical situations; the tendency to follow their reasoning in a linear causal sequence; the tendency to use the ideas having a range of connotations which can be different and considerably more extensive than those used by scientists; and the tendency to call upon different ideas to interpret situations which a scientist would explain in the same way. Some of their ideas are prevalent and transferable across various topic areas (Driver et al., 1985). These tendencies are called students' world views. In evolutionary biology, unexceptionally, there are several world views running through students' reasoning for various evolutionary concepts. Anthropomorphic and teleological worldviews can be discovered across the concept of fitness, evolution, adaptation, and change in a trait (Bloom, 1989; Tamir and Zohar, 1991; Robinson, 1994; and Anderson et al, 2002). Anthropomorphism is the worldview of Lamarckism (Greene, 1990 and Robinson, 1994). Following is the example of anthropomorphic reasoning; "bacteria have shown considerable ingenuity in developing resistance to antibiotics" (student, cited in Anderson et al, 2002: 953).

A number of researches also show the use of teleology in student explanation (Tamir and Zohar, 1991; Robinson, 1994; Anderson et al, 2002; Moore et al., 2002). Teleology is the worldview behind Creationism (Greene, 1990 and Robinson, 1994). The study of Moore et al. (2002) indicates that 126 university students referred to evolution as purposive adaptive processes and the goal directedness. These are presented as an internal, inherent attribute of individual organisms or of populations of species or, less commonly, externally as a conscious driving force or greater design. The students' world view of evolution is extended by the study of Passmore et al in 2001. Together with her colleagues, she found that the students viewed evolutionary change as absolute, automatic, all-or-none or deterministic process; "they will survive", "they all reproduced" rather than in contingent and probabilistic language such as "they had a better chance", "they were more likely to reproduce". The latter notion implies a lack of understanding of the uncertainty inherent in natural selection.

Models of evolution

Several models of evolution have been proposed to explain diversity amongst organisms, the origin and history of that diversity, and the natural processes by which it has developed and by which it is sustained (Skelton, 1993). A noteworthy amount of research shows that students, like scientists and western thinkers, hold a number of similar models to explain evolutionary phenomena. These various models are continuously judged by a community of scientists. There is neither right nor wrong in judging models. Rather, the scientists ask whether the model is acceptable or unacceptable by looking at its explanatory and predictive powers and consistency with other knowledge (National Centre for Mathematics and Science, n.d.). More than one theory may be an acceptable explanation for the same phenomenon. Darwinism and its extended version, Neo-Darwinism, are considered to be the most acceptable theory for explaining the evolutionary process by scientists (Ruse, 1989; Steele et al., 1998, Futuyma, 1998) and science education researchers (Clough and Robinson, 1985; Settlage, 1994; and Passmore et al., 2001). However,a number of researches on student understanding of evolution indicated that a number of students preferred to use Creationism and Lamarckism to explain evolutionary phenomena as follows.

Creationism

Creationism is a doctrine or theory holding that matter, the various forms of life, and the world were created by God out of nothing and usually in the way described in Genesis. Scott (1999) disagrees with the creationism/evolution dichotomy. Rather, she encourages the public to see creationism and evolution as lying on a continuum, with creationism at one end and evolution at the other. There are several forms in creationism with arguments between proponents of each form (Isaak, 2000). The continuum is illustrated in Figure 2.2.

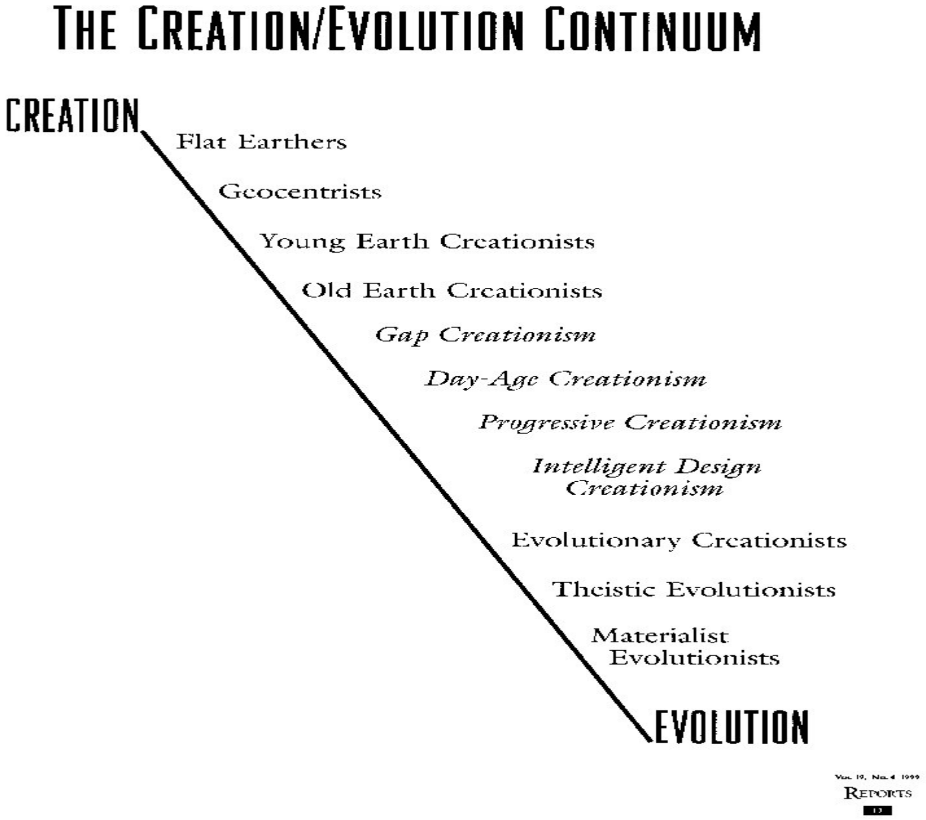


Figure 2.2 Creationism/Evolution Continuum
Source: Scott (2002)

In Figure 2.2, Flat Earthers, Geocentrists and Young Earth Creationists are clustered at the extreme end of the creation side. Their beliefs are based entirely on a literal reading of the Bible and they reject all of modern physics, geology, chemistry as well as biology (Berra, 1990). For example, Flat Earthers believe that the shape of the earth is circular and flat, not spherical. Based on the Bible, they refer to the "four corners of the earth" and the "circle of the earth". Although Geocentrists accept a spherical earth, they deny that the sun is the centre of the solar system. Only Young Earth Creationists seem to have a greater voice than the first two groups in driving anti-evolution. They have dressed creationism up in scientific terminology and fleshed out "Creation Science" through a number of books and pamphlets (Berra, 1990). Young Earth Creationists argue that the earth is from 6 to 10 thousand years old and refute the concept of biological descent with modification.

At the other end of the continuum lie Theistic Evolutionists and Materialist Evolutionists. Theistic Evolutionists believe that God creates through evolution. They accept most or all of modern science, though they provide a space for God for some things outside the realm of science, such as the creation of the human soul. This position has been promoted by Pope John Paul II (1996). Materialist Evolutionists hold a non-religious, neutral view; neither anti-religious nor pro-religious. It is neutral because supernatural forces are outside of the realsm of causation of natural processes.

Interestingly, at the middle of the continuum, a compromise between the two ends is found. Progressive Creationism blends Creationism with modern science. Progressive creationists do not question scientific data such as the age of the earth, the long period of time it has taken for the earth to come to its current form. Unlike Young Earth Creationists, they believe that different kinds of living thing are separate creations, not having been created all at once. They support their idea by evidence from the fossil records showing the appearance of different organisms at different times. They believe in evolution that can occur within a kind (according to their idea, kind is like a hierarchical family). The micro evolutionary processes; mutation, recombination, natural selection, genetic drift leading to a differentiation within a kind are accepted. A significant amount of research indicates that the majority of students embrace creationism in the middle of the continuum, rather than at the two extreme ends; they have some forms of explanation combining of evolution and creationism (Bloom, 1989; Greene, 1990; Dagher and BouJaoude, 1997; Downie and Barron, 2000; Woods and Scharmann, 2001; Moore et al., 2002). Greene (1990) found that although a number of students in his study supported theism, a belief in the existence of God, they accepted the possibility of change. In the same direction, Dagher and BouJaoude (1997) discovered the compromise between evolution and creationism in their students' answers.

The extreme creationist view, Creationism (young earth) held by students was reported by a number of studies, for example, the study of Bloom (1989), Dagher and BouJaoude (1997), Dowie and Barron (2000), Woods and Scharmann, (2001) and held by teachers by the study of Rutledge and Warden (2000) and Rutledge and Mitchell (2002). These studies show that the students rejected the idea that species can change from one kind to another. They explained that a change is directed by an outside agent; God and creator, for the improvement of species. Some of these students did not use the words “God” or “creator” explicitly. Rather, they mentioned an outside agent such as “nature”. To these students, natural selection is nature as an outside agent selecting individuals who are in need of becoming the beneficiary of helpful changes. They explained that all kinds of living things on the earth were created at once. Rutledge and Warden (2000) studied the acceptance of evolutionary theory of 989 biology teachers in Indiana State, United State. They found that the evolution of man is the concept least accepted by the teachers. Many of the teachers they surveyed believed that man was created by God.

Lamarckism

Lamarck (Strickberger, 1996) explained evolutionary change by saying that organisms developed a trait because they could sense the needs of the environment. The organisms respond to a particular environment by changing or developing the trait in appropriate adaptive directions, mostly from simple to complex. Development of the trait is the gradual process; the quality of the trait, over generations, is gradually developed. Environment accounts for the origin of variation among members of a species. Lamarck proposed two universal mechanisms; Principle of Use and Disuse and The Inheritance of Acquired Characters, to explain the origin of organic change and their transmission to further generations.

A number of previous studies indicate that Lamarckism is the most common alternative conception held by students (Deadman and Kelly, 1978; Brumby, 1984; Clough and Robinson, 1985; Bloom, 1989; Bishop and Anderson, 1990; Greene, 1990; Settlage, 1994; Bizzo, 1994; Robinson, 1994; Anderson, et al 2002). Greene (1990), for example, found out that 110 from 322 students or 34 per cent of students explain evolutionary change by Lamarckism. To these students, any outside information was considered the changing process or the process was linked in some ways to the idea of need or changing environments. The process does not generate any but the trait of focus and the individuals with trait are not compared with any having the ancestral trait. Greene described the idea of selection by these students as Nonfunctional Selection (61 per cent) and Nonselection (39 per cent). Students hold Nonfunctional Selection when they consider a trait is already deemed an advantage and the role of selection is only to confirm that the trait is an advantage by allowing individuals with the trait to survive. Nonselection described the students who did not make a logical connection between survival and death and the definition of traits as advantageous or disadvantageous, or not mention survival or death. The finding of Greene confirms Brumby's study in 1984 which discovered that more than 70 per cent of students he interviewed based their explanations on Lamarckian view.

Fundamental concepts of evolution

To understand the process of natural selection, the students must have had a sound understanding of the fundamental concepts of each component of natural selection. Natural selection comprises 5 components; origin of variation, role of variation, change in a trait, role of environment, and speciation. The fundamental concepts of these components addressed in previous research include evolution, population, fitness, and adaptation. These concepts have been used in everyday conversation where meanings are different from when they are used in an evolutionary context (Bishop and Anderson, 1990).

Evolution

In a biological sense, evolution is defined as genetic changes in populations of organisms through time that lead to differences among them (Strickberger, 1990). A significant number of studies reveal the gap between scientists' views and students' perceptions (Clough and Robinson, 1985; Bizzo, 1994). For example, Bizzo (1994) interviewed eleven students in São Paulo, Brazil, to investigate their ideas on evolution. He found that they held a variety of views but all deviated from the scientific view. The students considered man as a central reference for evolution.

When asked to provide examples of evolutionary change, the students gave a human example: “evolution is the process that transformed an ape into man” (Bizzo, 1994: 543). Some of them describe evolution as progress, improvement, and growth. The students gave various reasons for living things to evolve; for example, to obtain better conditions of life, to improve the performance of organs, organisms, or populations; to increase the size of organisms or populations; learning, social life, good manners, and moral virtues. Bizzo also found that the students could not distinguish between biological and cultural evolution. They saw all human artefacts as part of the same process of evolution. They considered all technology as part of the same process of adaptation that adjusts humans to environmental conditions.

Population

To evolutionary biologists, populations are the units of evolutionary change (Rothwell, 1988). The characteristics of a population are that its members tend to mate with one another more frequently than with individuals from other populations. Population members share a gene pool, which is the total of all the genes carried by all the breeding individuals in a population at a given time. Previous studies reveal students’ non-scientific views of population (Greene, 1990; Anderson et al., 2002). Greene studied pre-service teachers’ understanding of natural selection by using evolution problems. These problems asked the students to explain how an ancestor without a given trait could have evolved into a present species with the trait, using the idea of natural selection. He found that the students viewed population as a collection of individuals representing a common type. This corresponds with Anderson et al.’s study (2002) in the notion that all members of a population are nearly identical. The students did not consider a population as a geographically localized group of individuals in a species that, in sexual forms, share a common gene pool (Strickberger, 1990).

Fitness

Bishop and Anderson (1990) and Anderson et al. (2002) found that the students had a non-scientific understanding of the concept of fitness. In an evolutionary context, it is generally used to express the relative capability of individuals (or genes) to produce surviving offspring. Any genetic trait that increases an organism's ability to produce surviving offspring also increases its evolutionary fitness. The previous studies show that students recognize favourable traits such as health, strength, and intelligence as contributing to fitness. They also think that organisms with many mates are biologically fit.

Adaptation

Although adaptation is a key concept in a modern biology, like many powerful ideas, it has been misinterpreted and misused (Skelton, 1993). Adaptation is a character that has been modified and is or was maintained as a result of selection for increased fitness (Strickberger, 1990; Bishop and Anderson, 1990). Adaptation is a population phenomenon, whereby a population changes over generations through the action of natural selection. Bishop and Anderson (1990) found that pre-service teachers understood this term as change in response to an environmental condition. The finding corresponds with that of Brumby (1984), Clough and Robinson (1985), Bizzo (1994) and Settlage, (1994). Adaptation refers to individuals altering, through their own efforts, their form, function, or behaviour during their lifetime. This idea is based on Lamarckism in which a change in a trait in one organism' life time is passed onto its offspring. The organism acquires an adaptive trait by improving or deteriorating within its life span and passes the trait from one generation to the next. Brumby (1984) found that even medical students had alternative conception on adaptation. They explained that pesticide resistance in insects by saying that the insects becoming *more immune*, rather than *more insects* becoming immune. Another alternative conception on adaptation was reported by Clough and Robinson (1985) who interviewed secondary school students in the United Kingdom. These students explained adaptation by teleological world view: that the organism adapts to achieve a purpose which is then fulfilled by the adaptation. The students also explained adaptation in anthropomorphic terms: animals consciously effect physical change in response to a changed environment. Some of the students understood that animals responded to the changed environment by seeking a more favourable environment.

Evolutionary Process

Many studies point to the students' difficulty in understanding evolutionary process (Brumby, 1984; Bishop and Anderson, 1990; Greene, 1990; Bizzo, 1994; Settlage, 1994; Rutledge and Warden, 2000; Passmore et al., 2001; and Anderson et al., 2002; Moore, et al. 2002). The current view of the evolutionary process is based on Darwinism, and its later modified version, Neo-Darwinism. They are evolutionary theories accepted by a community of scientists (Ruse, 1989; Williams, 1996). These two models use natural selection as the mechanism of evolution. Neo-Darwinism is the synthesis of modern genetics and classical Darwinism (Reid, 1985; Spetner, 1996; Williams, 1996; Steele, Lindley, and Blanden, 1998); integrating molecular genetics and population genetics to explain the genetic basis of the process of natural selection, demonstrate how the organism passes on its traits to the offspring and how the genetic structure of a population changes through time. Neo-Darwinism is the model that this study is based on. Previous studies show students' misunderstanding of various components associated with the process of natural selection. These components are the origin of variation, the role of variation, change in a trait, the role of environment, and speciation. The findings of student understanding of each concept are discussed as follows.

Origin of variation

Passmore et al. (2001) studied high school students' descriptions of populations to determine how they thought about variability before and after a selection event. They noticed that prior to instruction, not many students explicitly mentioned the concept "variation" in their explanations. This is consistent with Greene's finding (1990). In Greene' s study, most students' explanations were classified as having a typological focus by the following criteria; only the trait of focus is created by the change process, if variations are created, the most negative variation is the ancestral trait and changes are created only when needed, and are not part of the normal definition of the population. When the students were asked to explain the origin of a variation, previous studies show that their ideas are far from the standard scientific conception. Bishop and Anderson (1990) found that random mutation and sexual recombination as source of variation within a population was omitted from students' explanations. This finding is similar to that of Brumby (1984), Bishop and Anderson (1990), Settlage (1994), Anderson et al. (2002) and Moore, et al.(2002)

Role of variation

Without the awareness of genetic variation within a population the concept that, "the variation within populations as an essential precondition for evolutionary change" is impossible for the students. Even though some of students consider the appearance of variation, they do not see how variability plays a role in the evolutionary process (Bishop and Anderson, 1990; Greene, 1990; Passmore et al., 2001; Anderson et al., 2002). Greene (1990) found that 26 percent of the students did not make a logical connection between survival and death, and no judgement was made between individuals having different traits.

Change in a trait

Bishop and Anderson (1990) discovered that many pre-service teachers participating in their research held alternative conceptions on how a living thing changes a trait. The students did not consider a change in a trait as the changing proportion of individuals with a discrete trait with each succeeding generation; rather, they understood that there was a gradual change in the trait itself, viewing the trait as improving or deteriorating from one generation to the next. The students thought that evolution molded or shaped the species as a whole, not considering the species on a population scale.

Role of Environment

A large number of students (Brumby, 1984; Bizzo, 1994) believe that the environment is the central source of variation rather than a selecting agent. These students explain that the environment itself causes living things to vary structurally, morphologically and behaviourally. This idea is rooted from Lamarckism which explains that species in different environments have different needs, and so use certain of their organs and appendages more than others. Rather regarding the environment as a selecting agent of the traits, the students believed that on the influence of the environment on the activities and habits of animals, and the influence of the activities and habits of the living bodies in modifying their organization and structure.

Speciation

In Scotland, over a twelve year period, Downie and Barron (2000) studied the acceptance of evolutionary biology among first-year university students. Their results indicate that 4 to 11 percent of the students stated that they rejected the occurrence of biological evolution. Most of the evolution-rejecters accepted the occurrence of within-species evolutionary changes. However most of them, over the years, did not believe in the origin of species (speciation). Another alternative notion on this concept was identified by Anderson et al. (2002) by saying that organisms could intentionally become new species over time: an organism tries, wants, or needs to become a new species.

Factors influencing understanding of evolution

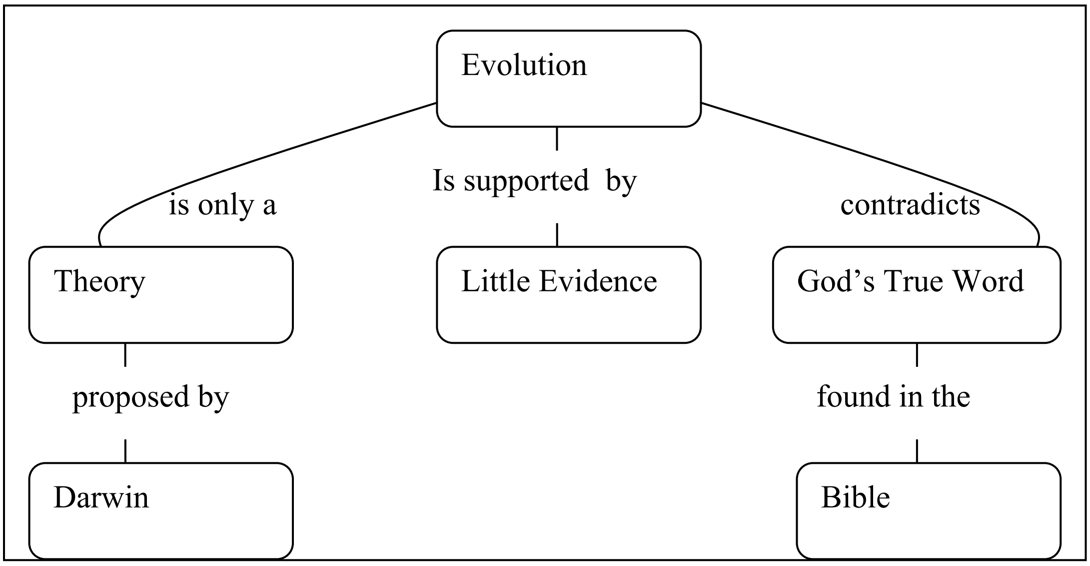
In this section, several factors influencing students acceptance and understanding of evolution from previous studies are discussed. The factors encompass religious belief, cognitive development, genetic content background, language, and textbook and presentation.

Religious belief

A number of studies have been done to investigate the effect of religious belief on student acceptance of evolution (Bloom, 1989; Osif, 1997**;** Dagher and BouJaoude, 1997; Downie and Barron; 2000; Rutledge and Warden, 2000; Woods and Scharmann, 2001; Rutledge and Mitchell, 2002). These studies indicate that religious belief is a big reason behind the rejection of evolution of a wide range groups of people; biology major students (Downie and Barron, 2000), medical students (Downie and Barron, 2000), pre-service teachers (Bloom, 1989), and even high school biology teachers (Osif, 1997; Rutledge and Warden, 2000; Rutledge and Mitchell, 2002). Downie and Barron (2000) conducted a longitudinal study on the attitudes of Scottish first year biology and medical students toward evolution and religion during 1987-1999. The number of students in each year increased steadily from 500 students in the late 1980's to 800 in 1998/1999. They found that over a twelve year period, the percentage of the first year biology students who rejected the occurrence of biological evolution varied from 4 to 11 percent and in one year surveyed 10 percent for medical students. The reasons for rejecting evolution by these students were the literal truth of a religious creation account that excluded evolution; conflicts and contradictions in the evidence for evolution, and the doubtfulness of theory of evolution. Downie and Barron discovered that the majority of the rejecters (86%) are religious.

This finding confirms the conclusion of Dagher and BouJaoude (1997) who explored undergraduate biology students' position toward evolution in Beirut, Lebanon in 1995. The population of Lebanon comprises Muslim 70 % and Christian including Orthodox Christian, Catholic, Protestant, 30 %. They found that a large number of students rejected evolution because of their strong religious belief background. Below are the student explanation presenting the argument from a religion and antievolution perspective (Dagher and BouJaoude, 1997) and the concept map (Figure 2.3) drawn by a high school biology teacher who rejected evolution in the study of Rutledge and Mitchell (2002: 24)

> As far as the origin of man my religious belief prevent me from accepting the principle of evolution but this does not mean that it is illogical; it means that in this particular aspect my belief is stronger than my reason (a student, cited Dagher and BouJaoude, 1997: 435)



<u>Figure 2.3</u> A Preventative concept map of a non-acceptance group
Source: Rutledge and Mitchell (2002).

According to the study of Dagher and BouJaoude (1997), religious beliefs of students affected their acceptance and understanding of evolution. Related to their conclusion, this study takes account of Buddhism and animism as the two major systems of belief in Thailand (Mahidol University, n.d.), in conducting research and interpreting data. Thai people are a deeply religious people. For the Buddhist majority, it underlies all activities and is the backbone of the Thai culture. Ninety percent of the population are Theravada Buddhists. Buddhism is the great eastern religion founded by the Buddha 600 years before the birth of Christ. Originated from India, subsequently propagated to Eastern and South Eastern Asia, Buddhism first appeared in Thailand during the third century B.C. in the area of the present day provincial capital Nakhon Pathom. Buddhism is in opposition to the former state religion, Brahmanism in terms of the avoidance of Brahmanism's emphasis on caste and dogma regarding sacrifice and ritual and the modification of Brahmanic concepts of kamma and rebirth. Although there exists today different Buddhist schools of thoughts reflecting different cultural attributes; Theravada School, Mahayana School, Vajrayana School, doctrinally there is absolutely no disagreement concerning the Dhamma as contained in the sacred texts, Tipitaka.

Like Sri Lanka, Myanmar, and Laos, Thailand is based on Theravada tradition. Dhamma, the teachings of the Buddha, is considered not solely as a cause, a principle, or a system of beliefs held to with ardour and faith, but also as a philosophy; a search for a general understanding of reality and values (Gorkom, 1969; Kalupahana, 1976; Phra Prayudh Payutto, 1995). In terms of nature of existence, Buddhism considers all things are constituted by integrated factors. There is no real self (or essence) in all things. When all of the elements composing one's being are divided and separated, no self remains. The being comprises five components called Five Aggregates; body, sensation, perception, mental formation and consciousness. Attaching to these five aggregate cause dukkhā or suffering. Buddhism considers all things existing in a constant flow or flux. Each and every component part comes into being due to the break up or disintegration of other component parts; and each of these parts does not have its own essence and arises and passes away one after the other unending succession, without absolute certainty or stability.

According to Buddhist teaching, all existence has three characteristics (tilakkhana); Aniccatā, Dukkhatā; Anattatā (Gorkom, 1969; Kalupahana, 1976; Phra Prayudh Payutto, 1995). Aniccatā is impermanence, instability, and uncertainty. It is a condition, which having already arisen, gradually breaks down and fades away. Dukkhatā is the state of suffering; a condition of pressure that arises and passes away, a condition of resistance and conflict, due to the fact that something that was created or fashioned in one way changes to become something else. Anattatā is all phenomena are not the self, and that there is no real essence, soul or self. Buddhism believes in rebirth taken place in most of the cases, although some people had made great progress in their spiritual development that they eradicated ignorance and other hindrances that the conditions for rebirth were not present anymore (Phra Prayudh

Payutto, 1995). The rebirth is not re-incarnation that refers to the transmigration of a permanent soul into another physical body. Buddhism does not talk about the existence of a permanent, unchanging soul that was created. Rebirth is conditioned by cause and effect. However, almost all Thais believe in reincarnation, hopefully to a higher form of life, leading ultimately to the achievement of nibbana. To this end they "make merit" by doing good deeds. Ways to make merit include giving money to beggars, releasing caged birds and giving food to monks who do their early morning "alms round".

Underlying Buddhism in Northern Thailand is animism (Mahidol University, n.d.) - the belief that all things, such as trees, stones and rivers, have living souls. A large proportion of Thai people especially in the northern and north-eastern areas, believe in the attribution of conscious life to objects. When they adopted Buddhism, they modified their basic belief of animism into the fold of Buddhism. Buddhism has managed to mould itself onto Animism in Thailand, producing an unusual blend of moral philosophy and superstition. Spiritual objects such as a house of spirits, a tree wrapped by colour clothes, and spiritual statues, can be found everywhere in Thailand. A house of spirits, for example, is mandatory to install a spirit house when building a new house. In fact the house is made for the spirit of the land. It calms the spirit and assures good blessings for the owner of the house. Another example of animism's belief in Thailand is a wrapped big tree. It means that a spirit inhabits the tree. The tree shall not be cut without warning the spirit in order to let him find another tree. There is often a certain spirit associated to a certain type of tree such as banana tree spirits and so on. To protect forests against logging, some monks ordain trees and wrapped them up with a thin orange cloth. Trees were then sacred.

Cognitive development

A number of studies examined cognitive development and reasoning ability as the factors influencing student understanding of evolution such as the studies of Lawson and Thompson (1988), Settlage (1994), Woods and Scharmann (2001), and Sinatra et al.(2003). Lawson and Thompson (1988) found that the number of alternative conceptions significantly related to reasoning ability ranging from concrete operational, transitional, and formal operational. They argued that students who have not reached the formal operations level, 12 to early adulthood, would implement Lamarckism to explain evolutionary events even having received the formal instruction. This stage of cognitive development produces a new kind of thinking that is abstract, formal, and logical.

In the study of Settlage (1994), his conclusion was drawn in the same direction as that of Lawson and Thompson (1988) in that cognitive development restricts student's ability to understand evolution. He found that high school students could shift from Lamarckism to Darwinism in the part of the appearance of genetic variation within a population and its role in evolutionary process. However, the students could not explain the origin of variation after being received the formal instruction. In the discussion section, Settlage explained this difficultly by linking to a child' Zone of Proximal Development (ZPD) of Vygotsky. "ZPD is the region between the ability of a child to learn a concept independently and the potential for learning a concept when the child's efforts are supported by someone with a fuller understanding, such as teacher or peer coach" (Wertsch, 1985 cited in Settlage, 1994: 456). Settlage stated that the concept of the appearance and role variation appeared within a ZPD in a great number of students who had been ascribed to Lamarckian or teleological explanation in contrast to the concept of the origin of variation or random mutation which appear within a ZPD for a few of the students.

He used a metaphor to explain that the transition from Need (teleological explanation) or Use (Lamarckism) categories to Variation category (role of variation) is shallower than that from Need or other categories to Mutation (origin of variation). Figure 2.4 below is the conceptual landscape representing the relative scientific acceptability of the categories of student responses in Settlage's study. To move from one category to another, the students would have to pass through the intermediate valley.

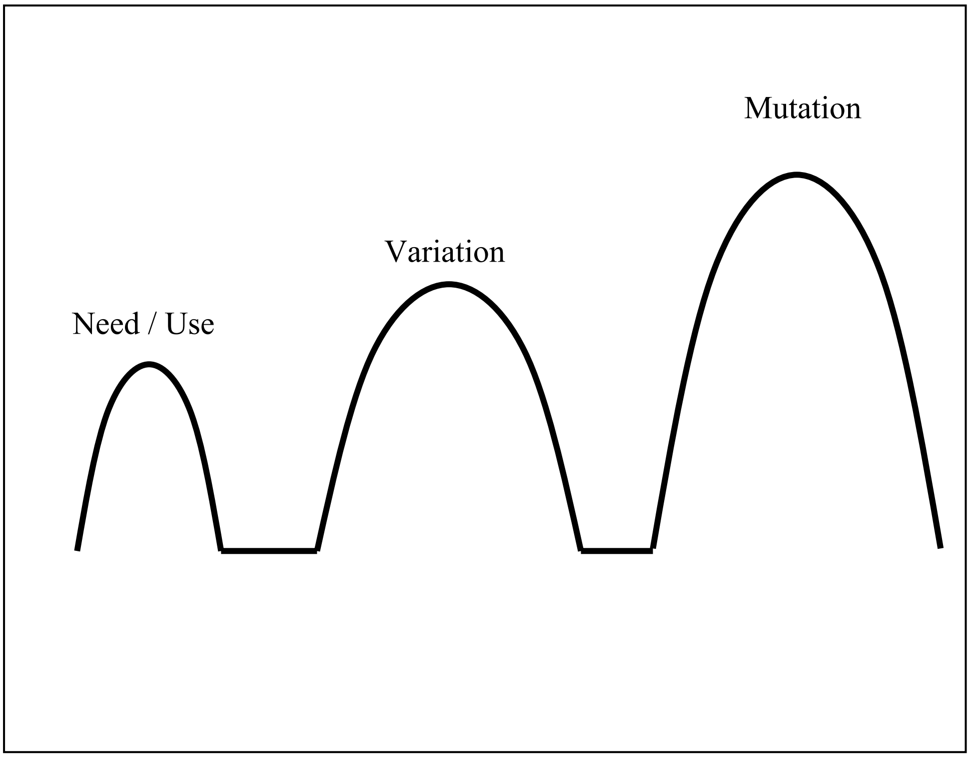


Figure 2.4 Conceptual Landscape of Evolutionary Process

Genetics content background

A number of previous studies discuss the need of genetic knowledge as a springboard for understanding evolution (Clough and Wood-Robinson, 1985; Bizzo, 1994; Settlage, 1994; Passmore et al., 2001). Halldén (1988, cited in Settlage, 1994) pointed out that the main reason for a difficulty in understanding evolution was the lack of the understanding of genetics. Especially Neo-Darwinism, students should already have scientific understanding of the concepts in genetics; mutation, gene recombination, inheritance, genetic variation, genotype, and phenotype, so they can understand the interplay among the interrelated concepts (Clough and Wood-Robinson, 1985; Bizzo, 1994; Passmore, 2001). Evolution and genetics are strongly connected. Population genetics, for instance, is used to understand the rates and dynamics of genetic changes within and among populations, including those that lead to adaptation and speciation (Futuyma, 1998).

Language

Language is one of the factors influencing student understanding of evolution (Bloom, 1989; Tamir and Zohar, 1991; Robinson, 1994; Passmore et al., 2001; Moore et al., 2002; Anderson et al., 2002). The English language, for example, is full of commonly used words that restrict the ability to speak clearly and unambiguously (Anderson et al., 2002). Anderson et al. (2002) exemplify this by the word "owl". When someone refers to "owl", it can mean different kinds of thing; the individual owl, the local owls, the local great horned owl population, or the great horned owl species. We rarely do take the time and make the effort to speak precisely in a daily conversation. Another language barrier is the meaning of the word. Depending on context it is spoken, evolution, for example, can mean different things. To layman and many of students (Dagher and BouJaoude, 1997), it is generally used to describe the process of change in a certain direction or the process of working out or developing or growth as in the phases like; the evolution of vehicle, the evolution of Thai society, the evolution of American politics. By attaching to this meaning, students explain biological evolution in terms of continuous change from a lower, simpler, or worse to a higher, more complex, or better state or a process of gradual and relatively peaceful social, political, and economic advance. In Thai language, many scientific terminologies also have a general meaning. When the term "Fitness" is used for example, Thai people always think of a fitness centre rather than the relative capability of individuals (or genes) to produce surviving offspring in the sense of evolutionary biology.

Textbook and presentation

The ways in which evolution is offered, shown, explained have an affect on student understanding of evolution (Jungwirth, 1975; Aleixandre, 1994; Jeffery and Roach, 1994; Bizzo, 1994; Robinson, 1994; Swarts et al., 1994; Anderson et al., 2002). Misconceptions of evolution found within biology textbooks were reported by Bizzo (1994). He found many figures of speech and figurative statements in the textbook could possibly be misinterpreted. Below is the several example of alternative conceptions in Bizzo' s study (1994) and IPST textbook (1990)

> Some fish began to make incursions on to firm land, probably looking for food; the fins were used as a support for the body weight, and as means of locomotion. *Gradually* they became adapted to terrestrial conditions; their fins began to be transformed into legs: this was the way the amphibians first appeared (Amabis and Martho, cited in Bizzo, 1994: 545).

> Forthcoming generations will retain and improve, through *slight* changes, the degree of adaptation achieved by their parents (IPST, 1990: 190).

> Mutation mostly produces damaging traits which are not favourable to the environment (IPST, 1990: 112).

Not only figures of speech and figurative statements, but also the difference in the number of evolutionary concepts appeared in various biology textbooks are discovered. Aleixandre (1994) evaluated the presentations of evolution in thirteen well-known, secondary biology textbooks from China, the United States, and the former USSR. The finding indicated the neglect of major themes and a considerable number of topics in evolutionary biology among the textbooks. This finding is consistent with the study of Jeffery and Roach (1994) who found that the coverage of evolutionary protoconcepts varies considerably among the published pre-high school textbooks examined. Jeffery and Roach emphasized the importance of the protoconcepts as a conceptual under structure that should be a part of elementary and middle school science curriculum. It is necessary to prepare students to understand evolutionary process and the significance of evolution. The under structure of evolution covers four areas; geological time, natural transition of earth environments, the variability and alteration of organism, genetic makeup, and the biotic potential of species (Keown, 1988 cited in Jeffery and Roach, 1994). However, Jeffery and Roach (1994) found that the majority of textbooks did not cover all areas of the under structure of evolution especially genetic makeup and biotic potential of species. This may not provide a strong framework for students before they come to learn evolution in high schools.

The methods used by teachers to teach or by researchers to probe student comprehension of evolution may cause student misinterpretation (Robinson, 1994; Anderson et al., 2002). Robinson (1994) critiqued Deadman and Kelly's (1978) and Clough and Robinson's study (1985) that drew only on animal examples to probe students' understanding of evolution and adaptation and inheritance. Robinson stated that there was need for further research related to student understanding of inheritance and evolution done in the context of plants. In addition, the language used in teaching and explanation may lead to misunderstanding among students (Jungwirth, 1975, cited in Anderson et al, 2002). The experts often use a metaphor to explain a complex process of evolution but they occasionally confused themselves and certainly can confuse their students.

Theoretical Perspectives of Learning

This section illustrates the development of perspectives on learning science and discusses how such development changes the way science educators view and conduct research in terms of philosophical, methodological and pedagogical focus. The researcher also argues that examining various perspectives of learning inclusively will enable science educators to a better understanding of the complexity of the learning process. The social constructivism and socio-cultural perspective of learning will be discussed to show how cognition is socially shared in enhancing scientific understanding of evolution.

Development of perspectives of learning science and the consequent changes of focus in research into science education

A number of theories of learning have been proposed. (Duit and Treagust, 1998; Bell, 1993; Cobern, 1993; Case, 1996). The major theories are behaviourism, personal constructivism, social constructivism, and socio-cultural perspective of learning. Shifting from one perspective to another impacts on how educational researchers conduct research. The goal of research and the nature of research questions are influenced by the particular mainstream of perspective of learning in a certain time (Bell, 1993; Cobern, 1993; Duit and Treagust, 1998; Cobern and Aikenhead, 1998). In the first half of the twentieth century, Behaviourism dominated thinking on learning. The research questions during that time, therefore, aimed to examine whether or not changes in a teaching procedure or in a curriculum lead to changes in students' performances. By the late 1960s, Piagetian had become prominent in educational research (Cobern, 1993). The Piaget's idea of learning includes the stages of cognitive development and the learning process by assimilation, accommodation and the idea of equilibrium. The Piagetian view of learning is the most contemporary constructivism and the basis of the later forms of constructivism (Duit and Treagust, 1998). Lawson's studies (1988) are the example of Piagetian-based research (Cobern, 1993). His research is the diagnosis of student mental stage and the creation of optimal conditions so that students could move from concrete to formal thinking.

In the mid1970s, the research in science education shifted from diagnosing mental stages to student conception on a particular science concept (Duit and Treagust, 1993). Current research is based on modifications of this perspective. A number of research studies, such as those of Driver (1983) and Driver et al. (1985) investigate the actual content of student conceptions. A variety of methods have been proposed to probe student conception (White and Gunstone, 1992). The common techniques are concept tests, concept mapping, interviews about events (IAE), and interviews about instances (IAI). The studies show that students strongly hold an alternative conception and resist change (Duit and Treagust, 1993). The constructivist view of learning was therefore given close attention by a number of science educators because it explained learning as a complex mental process. According to constructivism, learning is a conceptual change (Bell, 1993). A model of conceptual change was introduced by Posner et al. (1982), extended by Hewson (1981), and reviewed by Hewson (1989). The model discusses conditions and context. Conditions need to be satisfied in order for a person to experience conceptual change. These conditions are met within a conceptual ecology, the context in which the conceptual change occurs and has meaning (Hewson and Thorley, 1989 cited in Bell, 1993: 25). This form of constructivism is called personal constructivism. In the early 1990s, the social aspect of learning was taken into account in the process of knowledge construction. By discussing with others, individual construction can be supplemented. Interaction and negotiation help an individual in reflecting, clarifying, elaborating and reaching consensus on a specific experience (Tobin, 1990). A number of social constructivist approaches, such as cooperative learning, cooperative learning and tutored learning, were introduced in science education research. These aim to enhance the social meaning-making process.

In the 1980s, the view that science represents a uniquely valid approach to knowledge, disconnected from social institutions, their politics, and wider cultural beliefs and values was strongly challenged by research in the history of science, the sociology of science, ethno science studies in cultural anthropology and contemporary science studies, and science education on the content of evolution (Dagher and BouJaoude, 1997, Lemke, 2001; Rutledge and Mitchell, 2002). The researchers from these studies came increasingly to see that science had to be understood as a very human activity whose focus of interest and theoretical dispositions in any historical period were, and are, very much a part of, and not apart from the dominant cultural and political issues of the day. This lead to an increasing interest in the socio-cultural perspectives of learning science since the late 1990s (Case, 1996; Bell and Cowie; Lemke, 2001). Like social constructivism, socio-cultural perspective views science, science education, and research on science education as social activities. It, additionally, argues that learning science is conducted within institutional and cultural frameworks (Lemke, 2001). Knowledge is not the thought of one person, rather it is socially negotiated by a group of people who belong to a culture of which the language is used for reflecting on what is done and known (Tobin, 1993). The implication of a socio-cultural perspective in teaching science is teaching students to be more knowledgeable about the economic, sociological, technological, and political role of science in the modern world. If we teach more rigorously about a science concept, but do not tell students anything about the historical origins of these concepts, or the economic impact of technologies based on them, it will be difficult to promote scientific literacy.

In terms of research orientation in science education, the key areas of socio-cultural research in science education in the last decade, by searches of the ERIC database in 1966-99 (Lemke, 2001) are social interaction perspectives mainly on classroom discourse, language and science education, minorities in science education and gender equity issues. The interpretive research, which is based on the socio-cultural perspective of learning, describes the conventions of culture and interprets its effect on student learning (Lemke, 2001). The socio-cultural perspective of learning is considered as the most urgent, challenging, and exciting agenda for science education in the first decades of the twenty first century (Lemke, 2001).

Perspectives of learning science

Behaviourism

According to the behaviourist theory, learning occurs when experience causes a change in an organism's behaviour (Woolfolk, 1998). The behavioural changes must be observable and measurable. The goal of bbehaviourism is to predict or control behaviour (Watson, 1913, reprinted in 1994). For behaviourists, the environment is the only stimulus which plays a role in changing organism's action. Putative internal causes and their cognitive constructs are rejected (Schwartz and Lacey, 1982; O' Donohue and Kitchener, 1999). Experimentation is the methodology of behaviourism (Schwartz and Lacey, 1982; Leigland, 1997; O' Donohue and Kitchener, 1999). Watson (1913, reprinted in 1994: 248) argued that behaviourism is a "purely objective experimental branch of natural science". The relationship between environment and behaviour is explained by inferring hypothetical, causal mechanisms, processes, or constructs, which might ultimately comprise an adequate theory. The theory is empirically testable by the use of controlled environment-behaviour interactions in the laboratory (Leighland, 1997). Classical conditioning by Pavlov and operant conditioning by Skinner are the classic examples of behaviourist studies.

Behaviourism, especially applied behaviour analysis, contributes to teaching and learning (Woolfolk, 1998; Fontana, 1995; Porter, 2000). Applied behaviour analysis is the manipulation of conditions that surround behaviour, so that a desirable behaviour is strengthened and undesirable behaviour is either no longer provoked or maintained (Porter, 2000). It is a useful tool for teachers in encouraging positive behaviour as well as coping with negative behaviour. Attention, recognition, and praise can be used to reinforce positive, appropriate student behaviour while negative reinforcement, satiation and forms of punishment can be drawn on with caution to reduce inappropriate behaviour (Woolfolk, 1998).

Behaviourism embraces scientific realism (Leigland, 1997) which believes in an absolute truth and tries to make contact with it apart from human functions, constructions, and behaviour (Nola, 1998). Behaviourists believe that knowledge is a fixed entity which is waiting to be acquired. New things are learned by the acquisition of facts, skills, and concepts (Woolfolk, 1998). However, Behaviourism has been criticized. Scientific realism has become a primary focus of criticisms by anti-realists (Nola, 1998). The anti-realists argue that there is no way to construe matters of fact, objectivity, reality or truth apart from matters of language and of historical, cultural and linguistic context.

Personal constructivism

Von Glasersfeld (1993) argued that constructivism is primarily an epistemology. Constructivism explains what knowledge is and where it comes from.

Constructivists are anti-realist (Nola, 1998), believing that knowledge is constructed by an individual on the basis of theorizing and experiencing. Knowledge is neither an absolute truth which originally exists in nature, nor an independent entity from the human mind (von Glasersfeld, 1993). An individual can not discover constructs so a model that fits a particular experience is constructed. Even when the model has numerous verifiable properties, it can not claim to be the truth or a fixed entity (Tobin and Tippins, 1993). Prior knowledge, variously termed as gutfeeling, naïve, intuitive knowledge, is used to make sense of experience (Tobin, 1990; Bell, 1993). An individual acquires prior knowledge when interacting with the environment and this is influenced by language, by culture, the physical environment, and by parents, peers and other people (West and Pines, 1985).

When scientific knowledge is introduced, learning involves the interaction between prior and introduced scientific knowledge. The prior and scientific knowledge may be in a conflict or congruent situation. Assimilation and accommodation of Piaget's theory of cognition can be applied to explain the making sense of these two inputs (von Glaserfeld, 1989). A new conception can be incorporated with prior knowledge by the process of assimilation; prior knowledge is replaced or reorganised, by the process of accommodation (Posner et al., 1985; Bell, 1993). Posner et al. (1985) emphasised that accommodation is a radical form of conceptual change. Individuals change a concept when they have become dissatisfied with their prior knowledge and find the new conception more intelligible, plausible, and fruitful (Posner et al., 1982). According to personal constructivist view of learning, individuals learn a new concept when they develop, resolve, or exchange concepts (West and Pines, 1985).

Knowledge, or understanding, is multidimensional (White and Gunstone, 1992). Using a single style test and a single numerical score, therefore, is not adequate to reflect what learners know and how they know it. Constructivist researchers rely on different probes to explore what is going on in the human mind. White and Gunstone collected a number of probing techniques as powerful tools to explore student ideas and enhance effective learning. These are concept mapping, Prediction-Observation-Explanation (POE), interviewing about instances and events, interviewing about concept, drawing, fortune line, rational diagrams, word association, and question production. Constructivist teaching encourages students to declare their existing ideas and interact with the scientific conceptions. These procedures have been outlined in conceptual change approach by Posner, et al. (1982), the generative teaching approach of Osborne and Freyberg (1985), the interactive teaching of Biddulph and Osborne (1984) and the generative science teaching of Witrock (1994).

Social constructivism

Knowledge acquisition is not only individual but also social meaning-making processes (Driver et al., 1994). The view of scientific knowledge as socially constructed, validated, and communicated has important implications for science education. Teaching science must integrate the ideas and practices of the scientific community and make these ideas and practices meaningful at an individual level. Resnick (1991) explains that social constructivism joins a social aspect of learning to personal constructivism; they are essential aspects of one another. Social constructivism challenges cognitive psychologists to rethink the knowledge construction process by raising two important questions; "How can people know the same thing if they are each constructing their knowledge independently and how can social groups coordinate their actions if each individual is thinking something different? (p. 1-2)". Language and communication become the principle focus, and if one is to believe the claim that "throughout most of their lives people learn and work collaboratively, not individually". Then a framework based upon co-operative learning and social negotiation may be useful. While such an approach does not deny a Piagetian perspective, it also contains a major strength in that it can help to form learning and that is appropriate to the culture in which it is to be implemented.

Vygotsky (1978), a Russian psychologist, is concerned with the social context of cognitive development. The social world in which the child is located plays a part in the knowledge construction process. Vygotsky emphasizes that language is a primary element of the interaction which helps an individual in reflecting, listening and justifying. In other words, verbal interaction resolves individual perturbations and results in a group consensus (Tobin, 1990; Bell, 1993; Hodson and Hodson, 1998). One Vygotskian notion, that has significant implications for peer collaboration, is that of the 'Zone of Proximal Development.' Defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978), it differs from the fixed biological nature of Piaget's stages of development. Through a process of 'scaffolding' a learner can be extended beyond the limitations of physical maturation to the extent that the "the development process lags behind the learning process" (Vygotsky, 1978).

According to social constructivism, people shape the kinds of interpretive process available to individuals by interaction with others in face-to-face discussion, in writing, pictures and gestures, involving argumentation, contradiction, negotiation, decision, judgment, and problem-solving activities. Social constructivist approach, therefore, stress the need for collaboration among learners. Group learning approaches such as cooperative learning, collaborative learning, and tutored learning are based on social constructivism (Linn and Burbules, 1993). To engage in cooperative learning, for example, each group member is responsible for their own part of a task independently and then completes the whole as a group. In collaborative learning, all group members jointly work out a single solution to a problem. Tutoring learning involves more experienced students helping less experienced students to gain expertise. A number of studies show the success of group learning in promoting cognitive skills such as decision-making and problem-solving and scientific understanding of a number of science concepts.

Previous Research on Teaching Evolution

This section discusses a number of teaching approaches used in teaching evolutionary concepts in previous research. In a particular, attention will be paid to those for models of evolution and evolutionary process, the two areas of difficulty in understanding evolution discussed early. Importantly, not all teaching approaches are suitable for teaching evolutionary concepts. To make a choice, biology teachers should consider the nature of concept, resources, materials, student age and academic background and context (Driver, et al., 1985; White and Gunstone, 1992; Bell, 1993). In a particular circumstance, one approach may better suit with one concept than the other. The resemblances and the differences among these teaching approaches as well as their advantages and disadvantages will be taken into account. This review is the analysis and synthesis of two kinds of document; the research studies which empirically examine the effectiveness of a particular teaching approach and the article written by practicing biology teachers sharing his or her ideas on teaching particular evolution concepts. Therefore, some teaching approaches from the second kind of documents, are not have research finding supported. At the end of this section, the researcher will discuss how social constructivism can be applied to teaching evolution.

Teaching models (theories) of evolution

Evolutionary theories are a mature and coherent body of interconnected statements based on reasoning, and evidence that explain a variety of observation. For example, descent with modification proposed by Darwin in 1859 was later considered to be one of the strongest theories in biological science as it was supported by hundreds of thousands of observations from palaeontology, biogeography, comparative anatomy, embryology, genetics, biochemistry, and molecular biology (Futuyma, 1998). Theories always evolve as they are confronted with new phenomena or observations; parts of the theory are discarded, modified and added (Futuyma, 1998). To be accepted in the community of scientists, a theory must explain, predict and be consistent with other knowledge (National Centre for

Mathematics and Science, n.d.). A number of teaching approaches for teaching evolutionary theory are suggested such as classroom role play of Duveen and Solomon (1994), concept mapping of Trowbridge and Wondersee (1994), paired problem-solving instructional strategy and historically rich curriculum of Jensen and Finley (1996), and a modelling approach of Passmore and Stewart (2002).

Duveen and Solomon (1994) employed a classroom role play to teach theory of evolution to15-16 year old students in United Kingdom. They called their activity as "The Great Evolution Debate". The role play was acted by students to illustrate the debate of the launch of Darwin's book, *The Origin of Species* in 1859. Historical characters were used to show the rage of ideas which were current at that time. Duveen and Solomon did not intentionally study the effect of this approach in promoting the understanding of Darwin's theory. However, they observed that by engaging with the role play, the students took an active part in their own knowledge construction. They found that the role play were encouraging. The teacher involved reported that students actually saw the cut and trust of scientific debate has a real meaning in the real world.

Jensen and Finley (1996) investigated the effect of one-week evolution curriculum on non-biology major university students' understanding of evolutionary theory. The curriculum based on paired problem-solving instructional strategy and historically rich curriculum. During a paired problem-solving activity, students were required to solve the problem individually on paper, discuss similarities and differences in their answers with a partner, and attempt to derive a common answer. The characteristics of a historically rich curriculum are to introduce students the three theories of evolution prior to Darwin's theory; Lamarck' s theory of inheritance of acquired traits, Paley's natural theology and Cuvier's teleology; to provide historical experiments against these evolutionary theories such as Dr. Weisman' s experiment of rat tails, Payne's experiments of raising fruit flies in total darkness and Loeb' s experiment involving salt concentrations and fish populations; and to encourage students to elaborate on Darwin's theory of natural selection. The result indicated that the use of the paired problem-solving instructional strategy in association with the historically rich curriculum increase students' understanding of theories of evolution.

Based on the modelling approach, Passmore and Stewart (2002) developed a course on the practice of evolutionary biology for high school students. Similar to the curriculum of Jensen and Finley (1996), this course encouraged students to examine, revise and assess of three models of evolution; Paley' model of intelligent design, Lamarck' s theory of use and disuse, and Darwin's model of natural selection. The students developed, elaborated, and used Darwin's model of natural selection. By the end of the nine-week course, students had made significant gains in their understanding of natural selection and its associated concepts; variation, selection, and heritability, more importantly they were able to weave their understanding of individual concepts together to develop explanations of change over time in populations.

In conclusion, the teaching approaches of models of evolution presented previously create classroom environments that have the look and feel of a community of evolutionary biologists. These environments not only promotes scientific understanding of the theory but foster higher order thinking, active learning and social meaning making. The teaching approaches provide numerous and varied opportunities to the students to examine, compare and contrast and judge the three models of evolution, solve realistic problems and engage in group discussion, public presentation and debate concerning their problem solving. Much of this was accomplished by having the students interact with data-rich cases such as the studies of Weisman, Payne, and Loeb. The students use these cases to verify and falsify models of evolution.

Teaching evolutionary process

According to national and international science education standards (AAAS, 1995; NRC, 1996, IPST, 2002), the students should be able to integrate the complex body of concepts to explain the process of evolution. These concepts include mutation, recombination, gene flow, isolation, random genetic drift, the patterns of change in the forms of organisms and in their diversity arising for the appearance and disappearance of species (Futuyma, 1998). For the sake of discussion, the researcher will divide the various teaching approaches by two interwoven topics; microevolution and macroevolution.

Microevolution

The teaching approaches of microevolution are experimental studies of Hiblish and Goodwin, (1994), and Green and Bozzone, (2001), concept mapping of Trowbridge and Wondersee (1994), a conceptual change-based teaching module of Desmates, Settlage and Good (1995), an inquiry based teaching module of Desmates, Settlage and Good (1995) and Sandoval and Morrison (2003), active learning of Staub (2002), story line of Kovach (2003), inquiry based activity of Leonard and Edmondson (2003), and technology-supported unit of Sandoval and Morrison (2003).

Hiblish and Goodwin (1994) used experimental studies to teach natural selection with university students in California, USA. The students had direct experience in performing experiments. They examined populations of the common Dandelions (*Taraxacum officinale*) from the two sections of a local cemetery in South Carolina that differ in the intensity and frequency of mowing. Hiblish and Goodwin discussed that most students participating in this exercise found the experiment a straightforward and convincing demonstration of natural selection. Hiblish and Goodwin discussed the strengths and weakness of using experimental studies in teaching natural selection. Although experimental studies provide students real life, predictable, measurable demonstration, it needs study sites; green house for 2 to 3 months for planting Dandelion seeds and need the students having background in statistics (Shoot-to-root ratio based on length and weight were calculated for each plant. Mean shoot-to-root ratio and their standard deviations were then calculated, and mean values for each population were compared using a t-test)

The experimental study is also employed by Green and Bozzone (2001) in teaching the concept of random mutation. The students participating in their studies were in university level in Colchester, USA. Experimental study was designed to test two hypotheses of mutation; the mutation hypothesis and the acquired immunity hypothesis. The experiment repeated the work of Laria and Delbruck in 1943. The student grew up a large number of parallel cultures of *E. coli* and put aliquots from each on Petri plates infected with virus. If the number of resistant cells fluctuated greatly from plate to plate (i.e. if the variance in number was high), the mutation hypothesis would be supported. If the numbers were similar among the plates, this would favour the acquired immunity hypothesis. Green and Bozzone (2001) stated that the experiment provides a good deal of additional pedagogical benefit. It challenges students to think about experimental design and the conclusions drawn link to a number of disciplines like evolution, cell biology and genetics.

Concept mapping is the intervention chosen by Trowbridge and Wondersee (1994) to teach evolutionary process with university students. In the first session of both the lecture and the laboratory course, the researchers trained the students the concept mapping technique, standard format for constructing the maps, exemplary concept maps and scoring criteria to be used by the instructor, and practiced and received feedback. Each student constructed a map once a week after a lecture. The instructor gave them five seed concepts and they were to add an additional five concepts and/or examples to the seed concepts in building their maps. The researchers found that the critical junctures in learning evolution can be identified by monitoring concepts map submitted after each of the course lectures. The students reported that they spent an average of 37 % more study time on the course than their previous biology courses. The use of seed concepts, micro mapping, a standard concept map format and a standard concept checklist make the strategy feasible for the instructor to implement and for the students to adopt.

Desmates, Settlage and Good (1995) conducted research to examine and compare the effect of conceptual change instruction and inquiry approach on student understanding of evolution. They replicated the work of Bishop and Anderson (1990) by using the same conceptual change teaching module to teach university students who enrolled in biology course for non-majors. The module was based on conceptual change theory. The materials helped instructors in accomplishing three tasks essential to overcoming critical barriers of student learning; diagnosing student deficiencies, creating dissatisfaction with misconceptions and providing opportunities for application and practice. They compared the effectiveness of conceptual change instruction with an inquiry approach. They used the inquiry based module developed by BSCS called Evolution and Life on Earth (ELE). Inquiry approach can be best characterized as having the students practice and implement the process and thinking skills associated with the work of professional scientists. The skills include forming, testing and evaluating hypotheses, predicting, observing and synthesizing new information and knowledge. The researchers found that conceptual change could help students increase their use of scientific conceptions insufficiently while inquiry approach increased conceptions significantly.

Finding of Desmates et al. (1995) is consistent with the study of Sandoval and Morrison (2003) who developed a four-week inquiry based and technology-supported unit on evolution and natural selection. The unit comprises two computer-based investigation environments to enable children to explore examples of natural selection. Each of the computer inquiry project asked students to explain a complex problem of natural selection. In the first environment, the students were asked to explain the episode of natural selection among finches. The second environment asked students to explain how *M. tuberculosis* bacteria were able to develop resistance to antibiotics. Each investigation is a guided inquiry activity. The students had to work collaboratively in groups of three or four to generate an answer for the complex question. During the investigation, the teachers and researchers encouraged students to record explanations, use data to support their claims, and justify. In addition, at the midpoint of each investigation, student groups reviewed each other's explanations using a rubric developed by the researchers and the teachers. The investigation environments were supported by a software program specially designed to help students organize their work and write their explanation. Students recorded their questions in this software, wrote explanations for each question, and were able to select specific pieces of data from an investigation environment (e.g. a scatter plot of beak sizes, a DNA sequence). Students' work was saved daily and their final electronic journals, including the questions they recorded, candidate explanations, and all of the day they selected as evidence, were printed out and turned in at the end of each investigation. Due to the primary purpose of this research (Desmastes et al. 1995) is to explore the effect of the unit on students' belief on the nature of science, the students' understanding of evolution before and after the unit were paid no attention . The researchers found that, overall; the students held a view of science as a search for right answers about the world. The inconsistency of individuals' responses undermines the assumption that students have stable, coherent epistemological framework. Students' expressed ideas did not change over the course of the intervention, suggesting important differences between students' talk during inquiry and their abilities to talk epistemologically about science.

To teach genetic drift, Staub (2002) used active learning approach with university students. The researcher developed a classroom exercise simulating the mechanism of genetic drift by drawing M&M milk chocolate candies from a bag. The bag of candies represents a gene pool. The different colour of M&M's represents different alleles of one gene. The exercise involves passing the bag of M&M's around the classroom and having students pour a relatively small sample on their desk. Students are simulating the founder effect, the establishment of a new population by a few original founders which carry only a small fraction of the total genetic variation of the parental population as what happens genetically when a few individuals are blown in a storm from the main land to an island. Informal evaluation indicated that this exercise readily captures students' interest and helps them understanding this concept scientifically.

In a different way, Leonard and Edmondson (2003) developed the inquiry based activity called "Hardy-Weinberg Equilibrium, Founder Effect and Evolution" to teach founder effect to high school students in Clemson, the United States. The activity was constructivist and inquiry based. The activity encouraged students to engage in inquiry processes; raising questions, collecting data, synthesizing data and reflecting upon data. This activity uses the tools of mathematics to investigate the effect of founder effect on evolution of the widow's peak in human. The activity started with students observing each individual in the class and determining how many have a straight hairline and how many have widow' peak. They determined the percentage of those with straight hairline and with widow's peak. The students calculate the frequencies of recessive gene, dominant gene, homozygous dominant and recessive genotype and heterozygous genotype. The teacher randomly sorted the class into four groups. Each group determined its group data and share these with the entire class. The students discussed how the appearance of widow's peak differs in each group. The results indicate the students could explain and apply mathematics to detect the changes in allele frequencies of a given population with and without founder effect.

Kovach (2003) taught natural selection by story line method with high school students. In this method, teacher explained how the class would act out the story of the peppered moth with six rounds representing the years 1860, 1880, 1900, 1920, 1940, and 1960. Two to four students were selected to act as birds. Their role was to find as many of the hidden peppered moths as possible. The remaining members of the class serve as individual peppered moths representing 1000 true moths. This activity captures student attention and helps them learn about the process of natural selection. The students could draw a graph of invented data and answer the questions related to situations.

Macroevolution

The teaching approaches for teaching macroevolution are the classification and evolution of Caminalcules of Gendron (2000), hands on/ minds on activity of Dodick and Orien (2003). Gendron (2000) used the classification and evolution of Caminalcules to teach the concept of a phylogenetic tree to non-biology major students in the United States. Caminalcules are imaginary organisms invented by Joseph H. Camin for the purpose of teaching evolution to college and high school students. He created them by starting with a primitive ancestor and gradually modifying the forms according to accepted rules of evolution. Gendron developed laboratory activity which consisted of three related exercises; classifying living Caminalcules into taxonomic categories; using the classification to develop a tentative phylogenetic tree; constructing a phylogenetic tree based on the fossil record. One of the main goals of the lab is to illustrate the intimate connection between the classification of living species and their evolutionary relationships. The researcher discussed that this approach was successful because the students enjoyed and could solve the complex problem. The students could explain and demonstrate how to classify living thing based on evolutionary relationship after constructing the phylogenetic tree.

Dodick and Orien (2003) developed a curriculum called “From Dinosaurs to Darwin: Evolution from the Perspective of Geological Time” for high school students in Israel. The curriculum is oriented by hands on/ minds on activity. The program is divided into three units; introduction, evolution and the fossil record, and independent investigation. In the introductory unit, there are two primary foci; defining the basic materials of a fossil investigation and understanding the relations between such materials so it is possible to reconstruct the environmental and evolutionary relationships of extinct species. The activity of the unit is field work assignment. The second unit aims to enhance scientific understanding of the distribution of fossils in geological time and encourage the students to tackle macro evolutionary problems. The activity of the unit is class debate and class presentation. In the last unit, independent investigation, the students conducted in-depth research projects concentrating on macro evolutionary change as witnessed in the fossil record. Sample research topics include: the evolution of birds, mass extinction, and modelling geological time. The format of such projects can be written papers, posters, class or multimedia presentation.

In summary, the teaching approaches for evolution in literature gave opportunity to students to actively involve in the social shared cognition activities; group experiment, drawing a concept map, classifying and drawing a phylogenetic tree. Teaching approaches for models of evolution, in a particular, commonly ask the students to clarify their thought and defense it to the group. The students had to listen and criticized others' based on evidence. By this social interaction, the students have encountered conceptual conflict and gradually constructed the scientific explanation of evolution by themselves with the assistance of their peers and teachers.

Implications of social constructivism on teaching evolution

To enhance scientific understanding of evolution, the teaching approaches, in which some overlap in principle and procedure, as presented earlier, ask students to actively involve in the process of socially shared cognition. A number of teaching approaches for the models of evolution, for instance, ask the students to work in groups or in pairs to examine the assumptions of the three models; Creationism, Lamarckism, and Darwinism or Neo-Darwinism, find the relationships between the models. In judging models, the students in collaboration with others have to determine the relevance and validity of each theory in terms of its capability of structuring and solving problems as well as its explanatory and predictable power. Additionally, in introducing students to evolutionary biology, these teaching approaches take into account a student's everyday culture such as language, beliefs, religions, as determining factors supporting or disrupting the acceptance of evolution.

Theoretical Framework of This Thesis

An extensive literature on student understanding of evolution indicates that, to a large number of students, evolution is a complicated concept to understand even after being taught. The students preferred to use non-scientific models; Lamarckism or Creationism to explain evolutionary process and their use of model was inconsistent depending on the contexts of question. The roots of such difficulties include: the process of evolution is the multifaceted and abstract concept about a historical event that cannot be demonstrated to students in a laboratory like other science concepts. In addition, the scientific explanation of evolutionary process, to many students, is contradictory to their personal belief. Previous studies indicate that students' worldviews and their prior experience shape their ideas on evolution. It argues that for the successful teaching of evolution, students' worldviews need to be taken into account religious beliefs, personal understandings and misconceptions.

The students should be encouraged to work through his or her previous models of explanation, building a coherent new understanding based on accurate scientific information through social process. Evolution will be better understood if the students have the opportunity to discuss their own values and beliefs with their peers and the teachers. Via social interaction, the students will be able to use evidence for evolution skilfully and impartially, organize models of evolution and articulates them concisely and coherently, distinguish between logically valid and invalid inferences and suspend judgment in the absence of sufficient evidence to support a decision. By this reason, in the current study, teaching and learning evolution is informed by the theory of social constructivism with their emphasis on the social aspect of learning and the focus on mediated action. It is used as the frame of reference of all phases in this thesis. It will be used in interpreting student understanding of evolution, designing and developing the intervention, and implementing and evaluating the intervention for the following research questions:

1. How do Thai students understanding evolution?
2. What is the existing situation of teaching and learning evolution in Thailand?
3. How do teachers implement the intervention?
4. Does the intervention that was based on social constructivist approach enhance scientific understanding of evolution?

In the next chapter, the methodology used to generate data on student understanding of evolution, existing of teaching and learning evolution, the intervention design and implementation with respect to social constructivism is outlined.

CHAPTER III

METHOD OF STUDY

Introduction

This chapter sets out the research methodology for the study. As the methodology of this study, interpretivism and its philosophical basis, characteristics, and research design, are first reviewed. These general ideas are then applied to the present research design. The chapter presents research framework, three phases of study; exploratory phase, intervention design and development, and intervention implementation and evaluation as well as data collection and analysis for each phase of study. Data generations methods used in this study are discussed; diagnostic test, interviewing, and classroom observations. In the end of chapter, the researcher discusses the ethical concern and efforts to enhance the trustworthiness of research outcome of this study.

A Review of Research Methodology: Interpretivism

Philosophical underpinning: naturalistic paradigm

Although the relationship between paradigms, postulates, and methods is complex, an understanding of the relationship brings the researcher insight into an inquiry (Maykut and Morehouse, 1994). A paradigm is a system of ideas giving some judgment about the nature of reality and is a way for understanding of whatever can be known (Guba and Lincoln, 1985; Maykut and Morehouse, 1994). The researcher works within the worldview of a particular paradigm. It provides the basis on which the researcher builds his verifiable knowledge and the framework within the research takes place. A paradigm encompasses a range of postulates or axioms which are individual assumptions stated positively and stipulated to be true. As rooted in a same paradigm, a variety of research methods share some specific points and a general orientation. Positivist and Naturalistic paradigm are considered to be two competing research traditions. As built on different set of underlying assumptions, a side by side comparison of their philosophical assumptions of positivist and naturalistic paradigms is helpful to understand the differences between the two paradigms (Guba and Lincoln, 1985; Maykut and Morehouse, 1994, Cohen, et al., 2000).

In terms of the nature of reality or ontology, positivism believes that a single tangible reality exists “out there”. Independent variables and process constitute the reality. Any of these variables can be studied independently of the others. Inquiry aims to predict and control the variables. In contrary, naturalistic inquiry seeks the multiple constructed realities that can be studied only holistically. Epistemologically, naturalistic paradigm believes in the interaction between the inquirer and the reality; the knower and the known influence each other. This is different from positivism whose reality is out there independently from the inquirer. The knower and the known are either extreme ends of a discrete dualism. In a logical perspective, positivism is different from naturalistic paradigm in the possibility of causal linkages and the possibility of generalization. Positivism believes that the truth in a cause and effect relationship or a linear causation will hold anywhere and at anytime, while naturalistic paradigm believes that the reality is in a state of mutual simultaneous shaping described by working hypotheses in individual cases. As for the purposes of research or teleology, positivism seeks verification or proof of propositions, while naturalistic paradigm seeks to discover and uncover propositions. In term of the role of values in inquiry or axiology, positivism believes that inquiry is value free and this can be determined by objective methodology employed, while in naturalistic paradigm, the inquiry is considered to be value bound as the inquiry is influenced by inquirer’s values and the values that inhere in the context. The differences in these philosophical foundations of positivism and naturalistic paradigm are the roots of the two influential approaches of inquiry, quantitative and qualitative research.

Characteristics of interpretative research

Interpretive research which is the research methodology of this study is based on naturalistic paradigm. It best suits this study as it enables the researcher to investigate a relationship between the knower; teachers and students, the known; the understanding of evolution and the context; Thai classroom environment. Interpretive researcher carries out research in natural setting with realities, in a complex mutual shaping, cannot be understood in isolation from their contexts, nor can they be fragmented for separate study of the parts without considering contextual value (Lincoln and Guba, 1985). The setting is purposively sampled in order to increase the scope of data so that the full array of multiple realities can be uncovered as much as possible. Purposive sampling also enables the researcher to more efficiently devise grounded theory as it takes sufficient account of local conditions, local mutual shaping, and local values.

In terms of method and research design**,** interpretative research allows research questions, guiding substantive theory or grounded theory, and design to emerge or to be grounded in data rather than set it up rigidly in advance. The researcher can not devise research questions and design until the patterns of multiple realities, the interaction between inquirer and the phenomenon, and the various value systems involved is adequately known (Lincoln and Guba, 1985). In addition, priori theories which are based on priori generalizations may provide a poor idiographic fit to the situation encountered. Interpretive researcher elects qualitative over quantitative methods to investigate reality because such methods can deal with the multiple realities and value patterns adaptively and sensitively (Lincoln and Guba, 1985). The researcher employs human instrument which encompass him- or herself and participants as primary data-gathering instruments because paper-and-pencil instrument can not sufficiently adjust to the variety of the realities encountered. Only human instruments, the intrusion of the instrument can be investigated and evaluated (Lincoln and Guba, 1985).

To analyze data, interpretative research usually uses inductive data analysis. This kind of analysis helps the researcher develop fully understanding of setting so that transferability, qualitative external validity, to other settings more accurately. Additionally, inductive analysis produces explicit, recognizable, and accountable interaction between the researcher and participants (Lincoln and Guba, 1985). This kind of research also produces negotiated outcomes: the researcher discusses his or her interpretations with the human sources from which the data have primarily been drawn. The participants in that context can best assess specific working hypotheses critically and understand and interpret the influence of local value patterns (Lincoln and Guba, 1985). The interpretation of interpretative study is virtually idiographic and reported in a case study mode since it can efficiently illustrate the influential local particulars such as the particular investigator-respondent interaction, the contextual factors, the local mutually shaping factors, and the local and investigator values (Lincoln and Guba, 1985). The report provides a thick description for transferability to other sites. However, transferring findings of one context to another needs to be considered carefully as the realities of the two contexts and their interaction between investigator and respondents and value systems maybe tremendously different. These make broad application of the findings tentative (Lincoln and Guba, 1985).

Multiple perspectives are inseparable from naturalistic paradigm by a number of reasons (Guba and Lincoln, 1985; Maykut and Morehouse, 1994; Creswell, 1998; Cohen, et al., 2000; Bryman, 2001). To validate inquiry outcome, the researcher always negotiate meaning and interpretation with participants from which data have been drawn (Guba and Lincoln, 1985; Bryman, 2001). This technique is called data triangulation (Cohen, et al., 2000). As dwelling in that context, the participants are in a better position to interpret complex mutual interaction-shaping and local value patterns. Additionally, they could help the researcher verify and confirm specific working hypotheses. In a classroom context, multiple perspectives mean that teachers and students can speak for themselves (Maykut and Morehouse, 1994) and due weight is given to their interpretations. This process of dialogue is required for both researcher and participants to bring their insights to bear upon the data (Creswell, 1998).

The use of only one data generation method, mainly a traditional quantitative assessment tool, is not an efficient way to produce to an adequately fine-grained description of both what learners known and how they build and revise that knowledge. For that reason, multiple methods of data generation have been brought into play in this study to build the thick descriptions of student conceptual frameworks (Southerland, Smith and Cummins, 2000). The use of multiple sources of data gives a richer and more faithful description of a learner's conceptions. Different methods of data collection often provide different insight into a student understanding. These insights should be complementary but sometimes appear to be contradictory (Patton, 1989; White and Gunstone, 1992; Southerland, Smith and Cummins, 2000).

Research design: case study

By means of direct observation and access to subjective factors such as thoughts, feelings and desires, case studies answer "how" and "why" questions in which hypothesis testing and surveys can not do so (Bromley, 1986 cited in Merriam, 1998; Yin, 1994; Merriam, 1998). Case studies can be understood by examining its constituents; process, end product and unit of study. It is the process which tries to describe and analyze phenomena in context. It, hence produces thick description; intensive and holistic document of analysis and interpretation of the context. Case studies are encountered with a bounded system. Consequently, the topic of case studies is specific, complex and functioning rather than general. Qualitative case studies are particularistic, descriptive and heuristic. Case study is likely to be the best suited to situations in which it is impossible to identify phenomenon's embedded variables ahead of time and separate them from their context (Yin, 1994). As a result, it investigates as many variables as possible and portrays their interaction over a period of time (Merriam, 1998). Case study can be used efficiently in monitoring process and determining causal explanation of the phenomenon (Reichardt and Cook, 1979; Merriam, 1998). To monitor the process, researchers describe the context and population of the study, investigate the extent to which the treatment or program has been implemented, provide immediate feedback of a formative type and the like, while causal explanation is drawn by discovering or confirming the process by which the treatment had the effect that it did.

To be particularistic, descriptive and heuristic, a wide range of methods for generating data such as testing, interviewing, participant observation, are employed in this study (Merriam, 1998). However, case studies usually use prose and literacy techniques to describe, elicit images, and analyze situations; therefore they are presented in documentation of events, quotes, samples and artifacts. Multiple case studies, one type of case studies, is used as a research design in this study. They involve with collecting and analyzing data from several cases (Merriam, 1998). Analyzing multiple cases with their great variation across the cases yield an in-depth understanding of a single-case finding, grounding it by specifying how and where and, if possible, why it carries on as it does (Miles and Huberman, 1994; Merriam, 1998). A cross-case analysis strengthens the validity, stability, and generalizability of the findings (Miles and Huberman, 1994; Merriam, 1998).

Research Quality: Trustworthiness

Within the framework of logical positivism, the criteria for judging goodness; internal validity, external validity, reliability and objectivity, are perfectly reasonable and appropriate. These criteria have their foundational assumptions rooted in the ontological and epistemological framework of positivist inquiry. However, these traditional criteria do not meet the basic axioms of naturalistic paradigm. The meaningful criteria for judging goodness and quality in naturalistic/constructivist inquiry are creditability, transferability, dependability and confirmability. These criteria are intentionally designed to parallel the rigor criteria that have been used within the conventional paradigm: creditability parallel to internal validity; transferability parallel to external validity; dependability parallel to reliability; and confirmability parallel to objectivity (Guba and Lincoln, 1989).

Credibility: qualitative internal validity

Based on the idea of isomorphism between findings and an objective reality in positivist paradigm, internal validity is defined conventionally as the extent to which variations in an outcome or dependent variable can be attributed to control variation in an independent variable (Guba and Lincoln, 1989). The internal validity is established by controlling and/or randomizing processes to diminish a number of threats such as history, maturation, testing, instrumentation, statistical regression, differential selection, experimental mortality and selection. Internal validity is unacceptable in naturalistic paradigm because of its realist ontology and the isomorphism between a study's finding and the real world. According to naturalistic paradigm, the reality is mentally constructed by stakeholders. For that reason, internal validity is replaced by creditability criterion. Instead of focusing on a presumed "real" reality, "out there", creditability establishes the match between the constructed realities of respondents (or stakeholders) and those realities as interpreted by a researcher and attributed to various stakeholders. Several techniques for increasing creditability are prolonged engagement, persistent observation, peer debriefing and member checks.

Researchers should have prolonged engagement at the site of the inquiry. This technique not only prevents misinformation and distortion but also establishes rapport with the stakeholders and assists the researchers immersing in and understanding the culture of that context. Together with prolonged engagement, persistent observation help the researchers identify the characteristics and elements in the situation that are most relevant to the problem or issue being pursued and on them in detail. In the same way, peer debriefing, discussing with a disinterested peer in extended and extensive discussions of findings, conclusion, and tentative analyses, reflects the researchers on their own posture and values and their role in the inquiry, facilitates testing working hypotheses outside the context. With those peers, the researcher can search out and try next methodological steps in an emergent design and this reduces the psychological stress that normally comes with fieldwork. Noting and challenging from the peers awake the researchers to monitor their own developing construction. Their construction should not be given privilege over that of anyone else. The most powerful technique used in establishing creditability of naturalistic inquiry is member checks which is testing hypothesis, data, preliminary categories, and interpretation with the stakeholders from whom the original constructions were collected. This gives them the chance to correct error of facts or errors of interpretation and offer additional information leading to further illuminate a given construction.

Transferability: qualitative external validity

In positivist paradigm, external validity is defined as the generalizability of the findings of a particular inquiry to other contexts or with other subjects (Guba and Lincoln, 1989; Cohen et al., 2000). Selection effects, setting effects, history effects and construct effect are their threats. To increase external validity, both sending and receiving contexts should be at least random samples from the same population. As the criterion parallel to external validity, transferability is based on the notion that, in different encountered contexts, realities to which one might wish to generalize exist in different forms in different minds. The different realities are rooted from different circumstances, history, value systems, and experiences. Transferability is an empirical process for checking the degree of similarity between sending and receiving contexts. It is always relative and depends entirely on the degree to which salient conditions overlap or match. To establish transferability, the researcher should present thick description: setting out all working hypotheses of the sending context, providing an extensive and careful description of the time, the place, the context, the culture in which those hypotheses were found to be salient. Rather by the inquirers, transferability is judged by others who may wish to apply the study of their own situation.

Dependability: qualitative reliability

In positivist view, reliability means the consistency of an inquiry and is a precondition for validity (Guba and Lincoln, 1989; Maykut and Morehouse, 1994; and Cohen et al., 2000). Therefore any careless act in the measurement and assessment process and psychological stress from the intensity of the process should be taken care of since they can threaten reliability. To establish reliability, researchers should assure that very repetition of the same instruments to the same phenomena will yield similar measurements. This means that reliability is based on the notion that phenomena are unchanging, which is unacceptable in naturalistic inquiry whose the phenomena are central to change; growth and refinement of construction. Consequently, dependability, its parallel criteria, comes as a replacement for reliability. Unlike reliability, dependability does not concern on methodological change and shift in construction. Instead, it views these changes as a part of increasing sophisticated constructions in an emergent design. However, such changes need to both tracked and publicity inspectable so the outside reviewer can understand what factors in the context led the researchers to the decisions and interpretations made during the process. This is called dependability audit.

Confirmability: qualitative objectivity

Objectivity is the criterion for neutrality; an inquiry is free of bias, values, and prejudice (Guba and Lincoln, 1989; Maykut and Morehouse, 1994; and Cohen et al., 2000). It should be determined only by the subjects of the inquiry and the conditions of the inquiry. To establish objectivity, the researcher should employ not only intersubjective agreement but also the methodology and its set of methods that render the inquiry impermeable to human bias and distortion such as experimentation. Explicitly, objectivity reflects the positivist epistemological position that subject/object dualism is possible. In naturalistic paradigm, confirmability is the parallel criterion to objectivity. It asserts that interaction is inevitable. Rather than focusing on the assurances of objectivity in method, confirmability embraces the assurances of integrity of the findings that are rooted from data themselves. This means that constructions, assertions and facts can be tracked to their source and the logic used to compress the interpretations into structurally coherent and corroborating wholes in a case study are available to be inspected and confirmed by outside reviewer. This process is called the confirmability audit.

Ethical concern

Ethical dilemma is an issue in educational and social research (Cohen et al., 2000). Researchers always consider the costs/benefits ratio; the social benefit of the research in extending theoretical and applied knowledge and their subjects' right and values potentially threatened by the research (Frankfort-Nachminas and Nachmias, 1992; Cohen et al., 2000). During the course of investigation, their "right to privacy" of respondents may be violated when they involve with the sensitivity of the information being given, the setting being observed, and dissemination of information (Diener and Crandall, 1978; Cohen et al., 2000). The sensitive information encompasses religion preferences, sexual practices, income, racial prejudices, intelligence, honesty, courage etc. The setting being observed, for example, the intrusions to people's homes without their consent is seriously violated and forbidden by law. Dissemination of information concerns the ability to match personal information with the identity of the research participants. Cohen et al.(2000) expand ethical problems to the research procedure (producing high levels of anxiety); methods of data collection (covert observation); and the nature of the participants (emotionally disturbed adolescents). These breaches lead to affronts to dignity, embarrassment, loss of trust in social relation and self-determination., and lowered self-esteem (Cohen et al., 2000).

Informed consent, confidentiality, and anonymity are employed by a significant number of studies for ethical reason (Cohen et al., 2000). Informed consent is the procedures in which individuals choose whether to participate in an investigation after being informed of facts that would be likely to influence their decisions (Diener and Crandall, 1978; Cohen et al., 2000). The consent should explain the procedure, purposes, risk reasonably to be anticipated, and assure that the person is free to withdraw consent and to discontinue participation in the project at any time without prejudice to the participant. In addition, it gives confidence to the participant that their identity will be kept from public confidentially and they, in final report, are considered anonymous so another person can not identify them from the information provided.

Design for Current Research

Introduction

This section discusses research framework of the study which includes three phases; exploratory phase, intervention design and development phase, and intervention implementation and evaluation phase. In the first phase, the section discusses a survey research, the research design of this phase, the structure and the development of probing instruments; Evolution Diagnostic Test and Evolution Fundamental Concept to diagnose student understanding of evolution and interviewing protocol and Current Situation of Teaching Evolution to explore teachers' and students' opinion on the existing situation of teaching and learning evolution in academic year 2003. In the intervention design and development phase, the guiding principles for instructional activities and the structure of the intervention called, Evolution Learning Unit (ELU) including its content, activities and duration are previewed. The full details of intervention design and development will be discussed in Chapter Five: Intervention Design and Development. In the last phase, intervention implementation and evaluation, the section discusses that workshop was set up to introduce and demonstrate ELU to biology teachers. The discussion goes to a multi-site case study, the research design of this phase and the researcher clarifies his role and responsibility during classroom observations. A number of criteria are then discussed for evaluating the intervention such as the results from testing, interviewing, and observing classrooms etc. The section describes the strategies adopted in this study to assure ethical concern and enhance the trustworthiness of the research outcomes.

Research Framework

The study is divided into three phases; exploratory phase, intervention design and development phase, and intervention implementation and evaluation phase.

The exploratory phase aims to explore Thai student understanding of evolution and explore the situation of teaching and learning evolution in Thailand. In the first phase, student understanding of evolution is explored by testing. Two classes from each of three schools took the Evolution Diagnostic Test (EDT) and the Evolution Fundamental Concept Test (EFCT) in February, 2004 (second semester, academic year 2003). These students had been exposed to formal instruction on evolution in accordance with the former curriculum (IPST, 1990). As for the survey on existing situation of teaching and learning evolution of the second phase, the students filled out a questionnaire called Current Situation of Teaching Evolution (CSTE) and the biology teachers of these students were in-depth interviewed on the issues.

The intervention design and development phase aims to design and develop an intervention called Evolution Learning Unit to promote scientific understanding of evolution. The intervention was designed during March-October, 2004 under the supervision of research committee which consists of three university lecturers: one from the faculty of science who specialized in the content of evolution; and the other two from the faculty of education who had expertise in curriculum planning and design, pedagogy, and assessment and evaluation, based on the test and survey results from the exploratory phase, the guidelines of school science curriculum development of National Science Curriculum Standards (IPST 2002), student background, Thai classroom context, and school policies.

The intervention implementation and evaluation phase examines how the teachers implemented ELU and the effect of the intervention on student understanding of evolution. In November 2004, a workshop was set up for the Grade 12 Biology teachers who had participated in the first of study. The workshop aimed to demonstrate the use of ELU and ask them to comment on it. In January 2005, in the second semester, academic year 2004, ELU was implemented by the three teachers. The researcher conducted multi-site case study to examine how ELU was implemented in the classroom setting and if the intervention could enhance student scientific understanding of evolution. In conducting a case study, participant observation was the key data gathering method. In the participant observation, multiple measures and data sources such as; testing, interviewing, regular classroom visit, were combined to make meaning of what happened in the classroom setting. These data was used in evaluating the effectiveness of the intervention not only in terms of the promotion of scientific understanding but also the practicality of the intervention, student and teacher satisfaction. The intervention evaluation leaded to the provision for ongoing revision of the unit.

The phases of study, research questions, instrument, and timeline are summarized in Table 3.1.

Table 3.1 Data Collection And Timeline

Phases of study and Research Questions	Participants	Variables and Instruments	Timeline
Exploratory phase *RQ I*: How do Thai students understand evolution? *RQ II*: What is the existing situation of teaching and learning evolution in Thailand?	Grade 12 students from three schools in Bangkok and Nontaburi	1. Understanding of evolution by EFCT and EDT 2. Existing situation of teaching and learning evolution by CSTE	February 2004 (Academic year 2003)
	Three teachers from the same schools	1. Existing situation of teaching and learning evolution by an interviewing schedule	July 2004 (first semester, academic year 2004)
Intervention Design and Development		Designing ELU	March - October 2004 (first semester, academic year 2004)

Table 3.1 (Cont'd)

Phases of study and Research Questions	Participants	Variables and Instruments	Timeline
Intervention implementation and evaluation	Grade 12 Biology teachers from the exploratory phase	Workshop	November 2004 (Semester break, academic year 2004)
RQIII: How do biology teachers implement Evolution Learning Unit? *RQ IV*: Does Evolution Learning Unit enhance student the scientific understanding of evolution?	Grade 12 students from the three schools of the first phase of study (a different group from those of the first phase)	1. Understanding of evolution by EDT, in-depth interviewing and classroom observation	January 2005 (Second semester, academic year 2004)
	The biology teachers	2.Implementation of ELU by participant observation (classroom observation, informal interview and document analysis)	January 2005 (Second semester, academic year 2004)

Data Gathering Methods

This section discusses the objectives, the process of development and the structure of all instruments used in the three phases of study. In addition, this section discusses data collection and analysis of the instruments. The instruments used in this study include (from Table 3.1):

1. Evolution Fundamental Concept Test (EFCT)
2. Evolution Diagnostic Test (EDT)
3. Current Situation of Teaching Evolution Questionnaire (CSTE Questionnaire)

4. An interview schedule to explore existing situation of teaching and learning evolution
5. Evolution Learning Unit (ELU)
6. Workshop and Teacher Support Meetings
7. Participant observation

Evolution Fundamental Concept Test

The Evolution Fundamental Concept Test aims to probe student understanding of five fundamental concepts of evolutionary process cited in literature (Brumby, 1984; Clough and Robinson, 1985; Bizzo, 1994; Greene, 1990; Settlage, 1994; and Anderson et al., 2002). The five concepts are:

1. *Population*: the scientific model of population is a group of sexually interbreeding or potentially interbreeding individuals which are distributed in the same geographical area. Members of a population share a gene pool.

2. *Genetic variation*: the scientific model of genetic variation is a phenotypic variance of a trait in a population attributed to genetic heterogeneity.

3. *Fitness*: the scientific model of fitness is the relative capability of individuals (or genes) to produce surviving offspring. The individuals with the genetic trait that increases their ability to produce surviving and fertile offspring have high fitness.

4. *Adaptation*: the scientific model of adaptation that leads to evolution is Neo-Darwinism that adaptation is a population phenomenon, whereby the genetic structure of a population changes over generations through the action of natural selection.

5. *Species*: Biological Species Concept (BSC) is the scientific model of species. According to BSC, species is the members of a group of populations that interbreed or potentially interbreed with each other under natural conditions.

EFCT is a multiple choice format. To do the test, the students first read a situation and then answer a question about that situation. The student has to interpret the situation and choose, the choice statement that most corresponds to their explanation. Each choice statement was derived from scientific and non-scientific models of explanation identified in previous research. The scientific and non scientific models behind each choice statement of EFCT are shown in a specification grid in Table 3.2. To determine the consistency of student understanding, each concept is repeatedly measured by four diverse contexts including a plant and various kinds of animal; *Proteceae*, galapagos tortoises, black robins, and canary islands lizards. There are 20 items in the test. Once EFCT and another two instruments, EDT and CSTE questionnaire which will be discussed shortly, were approved by advisory committee, they were then field tested with a class of Grade 12 students at one school in Nontaburi, Thailand in November 2003 before final administration in the end of January, 2004. The students were asked to give comments on the appropriateness of evolutionary situations, questions, choice statements, language and time. The students indicated that the tests were too academic and difficult to understand. Therefore in order to enhance student understanding, the contexts and the choice statements were shortened and simplified and the use of technical terms was avoided. EFCT was subsequently revised accordingly. EFCT is available in Appendix A.

EFCT was administered in the exploratory phase in academic year 2003 after the students had finished evolution unit by the former science curriculum (IPST, 1981) along with EDT and CSTE. The students took EFCT before the other instruments. They were allowed fifty minutes to complete this test. Student response was analyzed by descriptive statistics, frequency and percentage of each choice statement (a model of explanation) and reported in bar graph with the assistance with SPSS computer program. The findings of the investigation are considered in making a decision if the intervention needs to review the fundamental concepts of evolution while discussing evolutionary process.

Table 3.2 The Test of Specification of Evolution Fundamental Concept Test

Topics	Scientific View	Non-Scientific View
1. Population	A geographically localized group of the same species which is capable of interbreeding. (1C, 6B, 11A, 16D)	1. A Group / The cluster of something; living or non-living or a combination. (1A, 6D, 11B, 16C) 2. A group of organisms representing a common type. (1D, 6C, 11D, 16A) 3. Only animals. (1B, 6A, 11C, 16B)
2. Genetic variation	The variation that is caused by difference in genetic material acquired by each individual. (2A, 7D, 12A, 17C)	1. The variation caused by aging. (2B, 7A, 12D, 17A) 2. The variation caused by outside agents such as decorating, shaping, pruning, repotting, and pinching. (2D, 7C, 12B, 17B) 3. The variation caused by diet and exercise. (2C, 7B, 12C, 17D)
3. Fitness	*Darwinism* The relative ability of an organism to survive and to leave offspring that can survive and leave offspring. (3D, 8D, 13C, 18D)	1. Healthiest and having longest life span. (3C, 8C, 13B, 18C) 2. Strongest and Biggest. (3B, 8A, 13A, 18B) 3. Most intelligence. (3A, 8B, 13D, 18A)

Table 3.2 (Cont'd)

Topics	Scientific View	Non-Scientific View
4. Adaptation	*Neodarwinism* A population phenomenon, whereby the population as a whole changes over many generations through the action of natural selection. (4C, 9B, 14B, 19C)	1. Individuals alter (consciously)through their own efforts, their form, function , or behavior to environmental condition. (4D, 9A, 14A, 19B) 2. *Lamarckism* Gradual changes in the traits themselves, viewing traits as improving or deteriorating from one generation to the next. The changes occur during the organism' s lifespan. (4A, 9C, 14C, 19D) 3. Creationsim (Young earth) The organism do not adapt themselves. All of them always have the best and most suitable structure designed by nature. (4B, 9D, 14D, 19A)
5. Species*	Biological Species Concept: An interbreeding, or potentially interbreeding, group of populations reproductively isolated from other groups. (5A, 10B, 15C, 20B)	1. Morphological Species Concept: Species are the group of organisms that are morphologically similar. (5D, 10A,15A, 20A) 2 Species are the group of organisms are distributed in the same geographical area. (5C,10C, 15B, 20D) 3 Ecological Species Concept: A group of organism that has the same environmental requirements. (5B,10D, 15D, 20C)

* The Biological Species Concept and Morphological Species Concepts are both widely used and considered to be acceptable in a community of practicing biologists. However, Biological Species Concept is accepted as a scientific model in the National Science Curriculum Standards (2002) and the target concept of the instruction.

Evolution Diagnostic Test

Evolution Diagnostic Test (EDT) was developed to investigate student understanding of evolutionary process for a large number of students. This test probes student understanding five components of evolutionary process according to Darwinism and Neo-darwinism which are derived from the analysis and synthesis of the tested content of the previous research (Brumby, 1984; Bishop and Anderson, 1990; Greene, 1990 and Anderson et al, 2002). The five components of evolutionary process include:

1. *Origin of variation*: there is the appearance of the genetic variation of inherited traits within a population. The variation is caused by random mutation and genetic recombination

2. *Role of variation*: the variation may produce beneficial, neutral or harmful trait in a population in a particular environment.

3. *Change in a trait*: among the offspring, those having most favorable trait to a particular environment tend to be most successful in producing young while the ones less well-suited are less likely to survive and less likely to produce offspring. The proportion of individuals holding a particular trait changes, not the quality of the trait

4. *Role of environment*: environment is a selecting agent, not the quality of a trait.

5. *Speciation*: natural selection causes two genetically isolated populations accumulate genetic differences so they become two distinct species.

As for the style of EDT, the researcher followed Conceptual Inventory of Natural Selection of Anderson et al. (2002). The EDT is in multiple-choice format. It consists 25 items. The multi-choice statements of the test are derived from scientific and non scientific models of evolution identified in literature and student responses in pilot interviewing. The scientific and non scientific models behind each choice statement of EDT are shown in a specification grid in Table 3.3. Each of component is measured repeatedly to address the consistency of use a model by five diverse contexts including animals, a plant and a microbe; colonial bentgrass, peppered Moths, guppies, *E. coli* and galapagos finches. This test style involves use of relatively long text in the question (evolutionary situation), interpreting, and choosing the choice statement that represents a particular model of evolution. EDT is available in Appendix B.

This test was first administered in the exploratory phase in academic year 2003 after the students had finished evolution unit by the former science curriculum (IPST, 1981) and again in the intervention implementation and evaluation phase before and after the implementation of Evolution Learning Unit. The students were allowed an hour to complete the EDT. In the first phase, EDT was used to identify student's conceptual difficulty of understanding evolution which is a need for designing an intervention but in the third phase in academic year 2004, EDT is used for a different purpose: to examine the effect of the intervention on student understanding of evolution. To analyse the data gathered by EDT, descriptive statistics; frequency and percentage of a particular model of evolution, was employed with the assistance of SPSS computer program.

In-depth interviewing was conducted to make sense of the findings of student understanding of evolution gathered by EDT in the third phase of study (before the implementation). The findings from testing show that, to explain a concept of evolution, the students did not hold a single explanatory model of evolution in their mind. They instead hold many and apply the one that most reasonable, suitable, and possible, to them, for a particular context and concept of evolution. To investigate the reasons of inconsistent use of a model across different contexts of question, five students from each school, after taking EDT for a week or two, whose answers on tests show inconsistent use of model across five contexts were drawn for the in-depth interviews. The interviews also elaborated student's test answer because students' answers on tests don't always show their true level of understanding. Sometimes they understand more than their answers indicate, and sometimes, despite their regurgitating the correct words, they don't understand what they choose.

Interview data was recorded by audiotape recorder. Transcription was completed soon after an interview had occurred. Pseudonyms were used to identify and indicate when the students were speaking. The information of the interviewee such as pseudonym; a description of the interviewee; the date of the interview; the time it occurred (start and finish); and a description of the physical setting; were included in the transcript. To analyze the data, the transcripts of all students were collated and grouped. The response of each question of all students is then compared to examine the differences and commonalities between the students' ideas.

Table 3.3 The Test of Specification of Evolution Diagnostic Test

Evolutionary Process	Scientific models	Non-scientific models
1. Origin of Variation	*Neodarwinism (N)* Heritable differences are caused by random changes (mutation, crossing over and independent assortment). (1A, 6D, 11D, 16B, 21B)	Creationism *(Gradualism) (CG)* Variation is created by evolution within a species. (1C, 6B, 11C, 16C, 21C) *Lamarckism (L)* Environmentally cause. The organisms respond to heterogeneous environment. (1B, 6C, 11B, 16A, 21D) *Creationism (Young earth) (CY)* Variation exists originally. It is the part of an initial population. (1D, 6A, 11A, 16D, 21A)
2. The Role of Variation	*Neodarwinism (N)* Variation leads to different reproductive success between individuals within a population in a particular environment. (2A, 7B, 12D, 17C, 22C)	*Lamarckism(L)* Variation has no role within a population. It doesn't have any effect on the survival and reproductive rate of individuals (2D, 7A, 12A, 17B, 22A) *Creationism(Young earth) (CY)* Variation has no role in a population. It is used to distinguish individuals within a population. (2B, 7D, 12C, 17D, 22D) Variation has no role within a population because, in the future, the individuals will still be the same species. (2C, 7C, 12B, 17A, 22B)

Table 3.3 (Cont'd)

Evolutionary Process	Scientific Models	Historical Models
3. The change of a trait	*Neodarwinism (N)* The favoured trait for a particular environment will establish in succeeding generations. Proportions of individuals with discrete traits change. (3B, 8D, 13B, 18A, 13C)	*Creationism (Young earth) (CY)* No change. The organisms with their existing traits are always suitable to all conditions of the environment. (3A, 8B. 13D, 18D, 23D) Creationism *(Gradualism) (CG)* An original type was created. The new type evolves from the original species. (3C, 8C, 13C, 18B, 23B) *Lamarckism (L)* The organisms make gradual changes in the traits themselves, viewing traits as improving or deteriorating from one generation to the next. (3D, 8A, 13A, 18C, 23A)
4. The role of The environment	*Neodarwinism (N)* Survival or disappearance of a trait due to selection by an environmental factor. (4D, 9A, 14D, 19D, 24C)	Dominant/Recessive Gene The trait controlled by a dominant gene will be more apparent than that controlled by a recessive gene in a population. (4B, 9B, 14C, 19C, 24A) *Lamarckism (L)* Environment induces organisms to change the quality of their characteristics. (4C, 9C, 14B, 19B, 24D) *Creationism(Young Earth) (CY)* The proportion of each variant is already fixed. (4A, 9D, 14A, 19A, 24B)

<u>Table 3.3</u> (Cont'd)

Evolutionary Process	Scientific Models	Historical Models
5. Speciation	*Neodarwinism (N)* The multiplication of species by isolating mechanism; premating and postmating, forming reproductive barrier to prevent gene flow between two populations. The two populations will diverge and become two distinct species. (5B, 10C, 15B, 20B, 25A)	*Creationism (Young Earth) (CY)* The original "kinds" of organism were perfect and any deviations will lead the species to be degenerative. (5A, 10D, 15D, 20A, 25B) *Lamarckism (L)* An inborn trend in all species to move from being simple towards being complex and perfect and their innate capacity will react to the special conditions in the environment. (5D, 10A, 15A, 20D, 25C) Mutation causes a new species (5C, 10B, 15C, 20C, 25D)

Current Situation of Teaching Evolution Questionnaire (CSTE Questionnaire)

Current Situation of Teaching Evolution Questionnaire (CSTE Questionniare) was designed to explore students' opinion on the existing situation of teaching and learning evolution in academic year 2003. The questionnaire consists of two sections; personal data and teaching and learning evolution. In the personal data, the students give the information about sex, age, grade point average (GPA), grade of biology in the previous semester, the use of biology in the entrance examination, favorite learning style, and learning resources. In the second section, the students are asked to reflect on teacher' s teaching strategy for a particular topic of evolution, the introduction to the lesson, questioning, the use of instructional materials and media, assessment, and the topics of evolution that the students did not understand (See Appendix C).

The format of the first section is a check list while that of the second question is in a Likert scale. The students are asked to indicate the degree of frequency of a particular teaching behaviour in a five-point scale; Never, Seldom, Sometimes, Often, and Always. Each degree of agreement is given a numerical value from one to five.

The content validity of the questionnaire was established by the advisory committee. The questionnaire as well as EDT and EFCT were tried out with a class of grade 12 students at one school in Nontaburi before final administration in the end of January 2004, second semester, academic year 2003 after evolution unit oriented by the former curriculum (1981 revised 1990) was over. The result showed that the students understood all questions and took about 30 minutes to complete the questionnaire. To analyze data gathered by CSTE, descriptive statistics; frequency and percentage, was used with assistance with SPSS computer program.

An interview schedule to explore existing situation of teaching and learning evolution

The existing situation of teaching and learning was also reflected by the teachers of the students from the three schools. The interview schedule was developed for the in-depth interviewing (See Appendix D). The content of the interview schedule was derived from the previous surveys on the current situation of teaching science in literature including curriculum, textbook, teaching methods, instructional materials and media, facilities, assessment, learning resource, and classroom management. In the end of the interview schedule, the teachers were asked about the problems about teaching and learning evolution and give suggestions on the better way of teaching and learning evolution. The teachers were also asked how they had prepared themselves for implementing the school based curriculum. The interview schedule was commented by advisory committee and then tried out with a group of doctoral students to ensure the understanding of questions, estimate the time for the interview. To analyze the data, the transcripts were collated and categorized. The response of each question of all teachers is then compared to find out the differences and commonalities among teachers' opinion.

Evolution Learning Unit

The intervention is called Evolution Learning Unit (ELU), a one-month instructional unit on evolution for Grade 12 students. The unit consists of 7 lessons covering 12 classroom periods (50 minutes each period) or one full month (3 periods per week). To design the unit, the researcher took into consideration the findings of the exploratory phase; Thai student understanding of evolution and the existing situation of teaching and learning evolution, the guidelines of developing school science program of National Science Curriculum Standards (IPST, 2002), and Thai classroom and school context. The unit is intended to promote student scientific understanding of evolution. ELU is designed to be a ready for use instructional package equipping the teachers with the lesson plans, student manual, and instructional materials and media. Each lesson plan contains the information about the content, learning outcomes, teaching guidelines, instructional materials, worksheets and suggestions on formative assessment. The lesson plan opens the opportunity for the teachers to adapt the lesson to meet their student need, classroom culture, instructional setting and resource.

The content of evolution of ELU is organized into 3 consecutive themes according to National Science Curriculum Standards (IPST, 2002); Models of Evolution, Microevolution and Macroevolution (Table 3.4). In the first theme, models of evolution, the students explore 4 major models of evolution; Creationism, Lamarckism, Darwinism, and Neo-Darwinism. They also study the evidence and the application of Darwinism and Neo-Darwinism, the scientific models. In Microevolution, the second theme, the students elaborate upon Neo-Darwinism, a new version of Darwinism that integrated genetics and other areas of modern biology. They review and work out allele and genotypic frequencies of a given population. They then examine the population at the equilibrium and the changing population by natural selection, non-random mating, migration, genetic drift and mutation. The third theme, Macroevolution, focuses on several key species concepts, types and mechanism of speciation. They then discuss macroevolution, the evolutionary change above a level of species and the application of evolutionary relationship to the classification of living things.

The activities of all lessons facilitate social interaction between teacher and students and among students. Group and whole class discussion are the key teaching strategies of ELU. Aligned with the standards (IPST, 2002), the intervention creates opportunities for students to seek information, discuss and explain models of evolution, evolutionary process and biodiversity. The organization of content and activities are briefed in Table 3.4. The guiding principle, the process of development, the content and activities of ELU are discussed in full details in Chapter 5: Intervention Design and Development.

Table 3.4 The Organization of Content and Activities of Evolution Learning Unit

Themes	Lessons	Activities	Periods
Theories of Evolution	Lesson One: The Development of Models of Evolution	Identify types of scientific knowledge and play Thodsakarn Games to classify ideas of people in the game into three models of evolution	1
	Lesson Two: Models of Evolution	Listen to the excerpts of writings of Paley, Lamarck and Darwin, find the assumptions of each model, compare and evaluate the models and use Darwinism to explain the adaptation of mangrove plants and animals	2
	Lesson Three: Evidence for Darwinism	Make a fossil and find the evolutionary linkage in the fossil of Archaeopteryx and study other evidence for Darwinism such as comparative anatomy, molecular biology, embryology, plant and animal distribution.	2
Microevolution	Lesson Four: Populations at Genetic Equilibrium	Identify phenotype, genotype and allele from given statements. Work out allele and genotypic frequency in Hardy- Weinberg problems and examine the changes in frequency over generations.	1
	Lesson Five: Evolving Populations	Carry out "Counting buttons" and work out allele and genotypic frequencies of a population over generation; examine the changes in allele frequency when the populations undergo and do not undergo natural selection.	2

Table 3.4 (Cont'd)

Themes	Lessons	Activities	Periods
Macroevolution	Lesson Six: speciation	Compare and discuss three definitions of species, Identify types of isolating mechanisms, discuss the modes of speciation; allopatric and sympatric speciation and explain the speciation of Galapagos finches and bread wheat	1
	Lesson Seven: Macroevolution	Classify Caminalcules, make a phylogenetic tree of the living and extinct Caminalcules based on their morphology and identify extinction from a phylogenetic tree and discuss why it happens.	3
Total teaching periods			12

Workshop and teacher support meetings

The biology teachers from the three schools participating in the first phase are asked to implement Evolution Learning Unit. Before implementing the intervention, the researcher set up a one full day workshop in late November 2004 to demonstrate the teachers how to implement ELU in their classroom practice. The workshop starts with the teachers reflecting on their current practice of teaching evolution and perceived and felt problems and shortcomings in the former curriculum (IPST, 1990). The findings of student understanding of evolution and the existing situation of teaching and learning evolution from the first phase of study and their implications for teaching evolution were presented and discussed. Based on the findings and the requirement of science education reform, the teachers were challenged to think about teaching evolution in education reform era. The research project and the intervention were subsequently introduced to the teacher as an alternative way of teaching evolution. The guiding principles of the intervention were discussed. Each lesson and its activities were demonstrated and the teachers were asked to comment on the demonstration.

The teachers were given opportunity to ask any questions about the intervention; either from the demonstration or from the materials that had been given to them two weeks earlier to read. In the end of the workshop, the researcher discussed his role in this study and then he summarized data collection and timeline to the teachers. To provide continuous support for the teacher, during the implementation in January 2005, teacher support meetings were held every weekend. The meetings were the place where they can raise problem, share their experience, and exchange their ideas on a practical aspect of the intervention after they have taught for a week. The details of this workshop and teacher support meetings were delineated in Chapter 6: Intervention Implementation and Evaluation.

Participant observation

Participant observation is a major data gathering technique during the implementation of ELU in three schools in January 2005, second semester, academic year 2004. It was used in this phase to investigate how the teachers implemented ELU in their classroom setting. The researcher tried to observe all Grade 12 classes of all schools with the seven lessons as much as possible, even though the schedules of some classes overlapped. By this technique, the researcher immersed himself in classrooms. The researcher had visited in the classroom a month before the implementation in Genetics Unit, to build up rapport with students and become part of the classroom. This aimed to gain a close and intimate familiarity with teachers and students and their practices through an intensive involvement during the implementation of ELU.

During the implementation, the role of the researcher was established as a participant-observer. The researcher did not act as a teacher. The researcher did not intrude teaching in progress. During whole-class discussion, the researcher observed the discussion as a member of the class. During group work, he participated in a group and observed what was happening within a group from the perspective of the group. After finishing each lesson, the teacher was asked to give feedback on the match between the instruction and student needs; the appropriateness of instructional content; sequence and pacing of instruction, teaching strategies (varied, interesting, challenging, involving active and cooperative learning), and formative assessment. These revealed the practical difficulties when the unit was put into practice. Feedback from the students in each lesson was also taken into account in the unit evaluation to examine whether the students understood and were satisfied instructional activities.

The participant observation involved a range of methods: informal interviews with teachers and students, direct observation, and participation in the life of the group, collective discussions, and analyses of the personal documents produced within the group, and self-analysis. Being more flexible and accessible, field notes was used to collect and record a wide range of data from the observations such as a diagram of the classroom, including objects and people within it and the activities and noted the lesson, the date location, and time of the observation session, who initiated questions, what kind of the questions are raised, the pattern of interaction between individual students, the teacher and the class, and the actions of the teachers and students. In the categorizing and coding process, the researcher develops a set of categories that provide a reasonable reconstruction of the data collected. The researcher refines the categories, explores the relationships and patterns across the categories for the understanding of the people and setting being studied.

Ethical concerns

Ethical issue is a topic of concern in this study. Informed consent, confidentiality, and the safety and welfare of participants were notified to the participants in an ongoing manner. Before testing, interviewing and implementing the intervention, the students, the teachers and the institutional representatives were informed about the aims of the investigation; the procedure and possible disturbances in such activities which may result from the conduct of the research. In interviewing students, for instance, the researcher explained the purpose, the procedure and implication of the interviewing. Additionally, the students were guaranteed that their identity would be out of reach of the public and their answers would not have any effects to their grades. The anonymity of teachers, students and schools was addressed in the interviewing by pseudonyms. At all steps of the study, the researcher was mindful of cultural, religious, gender and other significant differences within the research population and school policies in the planning, conducting, and reporting of their research. By this concern, the researcher avoided all forms of harassment to the participants; not threatening students, research assistants, the teachers, people involved for any advantages in conducting research. The participants were informed that they had a right to participate or withdraw from the study at any stages. The researcher kept updated the representatives of institutions about the progress and any significant changes in the research program. At the end of the study, the researcher reported the findings to all relevant stakeholders; teachers, the head of science department, and institutional representatives. In favour of generalizability, the researcher communicated the findings and the practical significance of the research in clear, straightforward, and appropriate language to the public.

Strategies to enhance the trustworthiness of the research outcomes

To increase creditability, qualitative internal validity, the researcher employed the triangulation of data and methods in order to enhance confidence in the ensuing findings. Data triangulation is a crosscheck of findings between time, space, and persons. An example of data triangulation (persons) in this study is in the survey of existing situation of teaching and learning evolution in exploratory phase that the researcher gathered the data from both teachers and students on the same issue. The creditability was additionally increased by the technique of member validation, in which the respondent was given a copy of the observations or interview to provide feedback. The researcher asked the teachers to validate his interpretation. The teachers corrected error of facts or errors of interpretation and offer additional information leading to further illuminate a given construction. Another example of data triangulation (time) is when the researcher made classroom observations during the implementation of ELU. The researcher observed each classroom regularly at least once a week (2-3 periods per week). This persistent observation helps the researcher identify the characteristics of the classroom and its elements with confidence. The methodological triangulation was addressed in the study when the researcher used a number of methods to study student understanding of evolution; testing, classroom observation, interviewing, and document analysis.

To establish transferability, qualitative external validity, the researcher wrote thick description to portray the situation in the three schools while the intervention was implemented. The classroom and school environment, background of teachers and students, school policies and other factors affecting teaching and learning in Grade 12 level such as entrance examination were described in details so the readers can evaluate the feasibility to apply the study of their own situation.

To address dependability (qualitative reliability), the researcher reported any changes during the intervention implementation in traceable and publicity inspectable ways so the readers can understand what factors in the context directed the researcher to decide and interpret in that manner during the process since the changes are a part of increasing sophisticated constructions in an emergent design.

To address confirmability (qualitative objectivity), this research assure the integrity of the findings that are rooted from data themselves. This means that constructions, assertions and facts presented in this study can be tracked to their source and the logic used to compress the interpretations into structurally coherent and corroborating wholes in a case study are available to be inspected and confirmed by advisory committee.

Summary of the Chapter

To answer the research questions, interpretive research is used to make sense student understanding of evolution and the teaching and learning evolution oriented by the intervention. The findings from this phase were implied for the guiding principles of the intervention design. The research employed a number of data gathering techniques to find out how the intervention promote scientific understanding of evolution of students such as testing and interviewing the students before and after implementing the intervention and classroom observation. The classroom observation is utilized to study the development of student understanding while they were interacting with instructional strategies and materials during the course of unit. Ethic was taken into consideration in all stages of this study. Analysis of Data from these different sources, persistent observation, and respondent checking were undertaken to enhance the trustworthiness of the research outcomes. The next chapter presents results of the first phase of study; student understanding of evolution and existing situation of teaching and learning evolution.

CHAPTER IV

EXPLORATORY PHASE

Introduction

This chapter describes the results and discussion of two surveys on student understanding of evolution and teachers' and students' opinion on the existing situation of teaching and learning evolution in Thailand in academic year 2003. The participants were 253 twelfth graders and their biology teachers from 3 schools in Bangkok and Nontaburi in February 2004. The surveys were carried out after Evolution Unit oriented by the former curriculum was over. The first survey aims to student understanding of evolutionary process and its fundamental concepts and study how the students used such models in a variety of evolutionary contexts. Evolution Fundamental Concept Test (EFCT) and Evolution Diagnostic Test (EDT) were employed in this survey. In the second survey, the teachers were in-depth interviewed about the existing situation of teaching and learning evolution in terms of curriculum, textbook, teaching strategies, instructional material, learning resources, assessment and their preparation for implement a school based curriculum in an academic year 2005. The students were also asked to fill in a questionnaire called Current Situation of Teaching Evolution (CSTE) to reflect on the same issues as their teachers did. In the end of this chapter, the implication of the findings for teaching and learning are discussed.

Student Understanding of Fundamental Concepts of Evolution

Results

In this section, the percentages of students choosing scientific and non-scientific models of the fundamental concepts of evolutionary process chosen by students are computed and described. The fundamental concepts include population, genetic variation, fitness, adaptation and species. This section also examines the use of these models in varied contexts of questions as shown in Table 4.1 by column.

Population

The scientific model, “population is a geographically localized group of the same species which is capable of interbreeding”, is the most common model chosen by 73, 45, and 65 percent of students in the contexts of Protecease, tortoise, and black robin respectively. However, in tortoise, the percentage of students choosing the scientific model is less by the combination of the percentages of scientific models: “population is everything”; “population is the organisms that look the same”; and “population is animal only”. In the other word, the majority of students did not choose the scientific model in this context as well as in the context of lizards where the percentage of students chose the scientific model and the model “population is animal only” by close percentages, 39 and 40 respectively. The combination of percentages of students choosing non-scientific model in lizards, is 61 percent.

Genetic variation

The majority of students used all different models to explain genetic variation in the varied contexts; “variation is the difference by nutrition and exercise” by 66 % in Proteceae, “variation is the difference by genetic material” by 89 % in tortoise, “variation is the difference caused by outside agent” by 49 % followed by 44 % of those choosing the scientific model in black robin, and “variation is the difference by aging ” by 44 % followed by 30 % of those choosing the model “variation is the difference by nutrition and exercise” in lizards. This indicates that student might not have been certain about the model to explain the concept.

Fitness

The most common model in contexts of all contexts is the scientific model, “fitness is the relative ability of an organism to survive and to leave offspring that can survive and leave offspring” by 89 % in *Proteceae,* 69 % in tortoise, 54 % in black robin and 67 % in lizards. In black robin, the percentage of a non-scientific model is noticeable, the model of “the fittest is the most intelligent” by 39 %.

Adaptation

The most common model used to explain the concept of adaptation is Lamarckism, by 35 percent of students in *Proteceae*, tortoise, and black robin. Although the scientific model, Neo-Darwinism is the second most common model, the combination of those of non-scientific model is much higher that the percentages of the scientific model. In black robin, for example, the percentage of scientific model is 27 % while that of the combination of non-scientific models is up to 73 %. In lizards, the most common model is the scientific model. However its percentage (36 %) is pretty close to that of Lamarckism (35%).

Species

The scientific model “Species is an interbreeding, or potentially interbreeding, group of populations reproductively isolated from other groups.” is most commonly found in all contexts; 61 % in *Proteceae*, 52 % in tortoises, 66 % in black robin, and 54 % in lizards. Obviously, the non- scientific model “species is a group of organism that has the same environmental requirements” is also found by a noteworthy number in all contexts; 32 % in *Proteceae*, 28 % in tortoise, 20% in black robin, and 22% in lizards.

Discussion

The students were expected to have a scientific understanding of the fundamental concepts of evolution before they took the Evolution Fundamental Concept Test (EFCT) because in the curriculum, they are required to have studied these concepts. However, they did not use a scientific model to explain the concepts especially genetic variation and adaptation in all contexts. Their understanding of fitness and species is still questionable. Although the majority of students used the scientific model to explain the concept of Population, a significant number of them used non-scientific models; “The Organisms That Look the Same”, and “Only animal”. This finding is consistent with the results in Greene (1990) and Anderson et al. (2002), in that the students viewed population as a collection of individuals representing a common type: all members of a population were nearly identical. Robinson (1994) argued that students were familiar with the animal contexts. Therefore, the students might transfer this familiarity to explain Population.

To explain genetic variation, the students did not use any model in a particular. The most common models in the four contexts are all different. The non-scientific models identified are: “Nutrition and Exercise”; “Physical Change”; and “Aging”. In Fitness, the non-scientific models used by a significant number of students are: “Strongest & Biggest”; “Healthy & Longest Life”; and “Intelligence”. In the Thai language, Fitness is a new word derived from English. It generally means a gym and describes physical competence. Thai students might transfer the Fitness in this sense to explain the concept in the test. In common with Bishop and Anderson (1990) and Anderson et al. (2002), this study finds that a significant number of students thought that the fittest individuals were the healthiest, strongest, and the most intelligent.

The students used historical models; Lamarckism, Creationism (young earth), and Progressive Creationism with a percentage similar to Neo-Darwinism to explain the process of adaptation. This finding corresponds with those of Brumby (1984), Clough and Robinson (1985), Bishop and Anderson (1990), Bizzo (1994) and Settlage, (1994). Bishop and Anderson (1990) explained that students understood adaptation was the result of the response to an environmental condition. Accordingly, adaptation is the process where individuals alter, through their own efforts, their form, function or behaviour during their lifetime. This explanation is based on Lamarckism and used in a teleological and anthropomorphic sense which derived from the use of term in everyday language (Halldén, 1988): the organism adapts to achieve a purpose which is then fulfilled by the adaptation. The organisms consciously change in response to an environmental condition.

In the concept of species, rather Biological Species Concept (BSC), the scientific model, a high percentage of students used other species concepts to characterize the concept of species; Ecological Species Concepts (ESC) and Morphological Species Concept (MSC). However, a significant number of students used BSC. This use may be influenced by the presentation of this species concept in the IPST textbook (IPST, 1990: 124). There are only two species concepts discussed in the textbook; BSC and MSC. The textbook discusses the weaknesses of MSC and argues that BSC is the most widely accepted species concept among practicing biologists. For this reason, the students may accept this argument and have used it in this test.

The use of different models in the different contexts is also found in the fundamental concepts of evolution. The choice of model is influenced by the match between the chosen model and the context provided. In Population, for example, the majority of students preferred to use other models than “Only animal” in the context of Proteceae because they might have thought that this model was incompatible with the context. The model stated that plant can not be a population but the context, itself, is a kind of plant. Consequently, the students did not choose this contradictory option. They might have thought that it was illogical to use this model when the question asked “Which is a population of Proteceae?” The question logically implied to the students that Proteceae, which was a plant, can be a population.

Genetic variation is another example of the use of different models in varied contexts. This indicates that the students did not fully understand this concept because they noticeably changed models throughout the contexts. They chose the model that was most possible and the best fit a particular context. The students used the model of “nutrition and exercise” over other models in Proteceae because they might be familiar with the relationship between plant and nutrition and accepted that plants grew at different rates in different soil conditions. Therefore, the student might be more confident to use this model to explain the variation and the cause of variation in plant. This finding supports the argument of Robinson (1994) and Anderson et al. (2002) that the students would respond to plant contexts differently from animal contexts. The use of plant context in probing student understanding and teaching would give rise to more accurate understanding of student conception. In this concept, Neo-Darwinism is the most common model only in Galapagos Tortoises. However, this context is used in IPST textbook (1990) to explain the mechanism of natural selection.

The textbook states explicitly that their two forms of carapace show genetic variation within a population of tortoise. The variation in carapace shape is heritable. Some of student might have recalled the phrasing in textbook and transfer it to the test without scientific understanding.

In fitness, the students may have thought that it was impossible to use other models with plants, especially the models of “the strongest and healthiest is the fittest” and “the most intelligent is the fittest”. Plants can not think and exercise. This fact makes the three other models irrational. In black robin, a significant number of students (39 %) used the model of “the most intelligent is the fittest” over other models. The fascinating and impressive story of black robins might imply to these students that the birds should have been wise and intelligent so they could settle and increase their population successfully in a new environment (see the excerpt below).

> The birds successfully settled in their new home. Old Blue (who lived to 13 years – more than twice the normal age) and permanent partner Old Yellow (the only viable male of the two then remaining alive) would prove to be an effective breeding pair. All 150 black robins alive today are descended from them. Old Blue saved the species.
>
> (Excerpt from EFCT: 3)

The students did not notably use a particular model over others to explain Adaptation because the patterns of profile in the four contexts are very similar. This indicates that students might use the same model consistently over the contexts. This finding is different from that of change in a trait which is conceptually similar. The students should have used the same models to explain the two concepts because they are considered to be the same process. In change in a trait, there are two different patterns of profile where the percentages of each model are entirely different. Interestingly, this difference may stem from either they conceptualize Adaptation and change in a trait in a different way or they responded to the questions of the two concepts differently: Adaptation (how did individuals adapt to an environment?); and change in a trait (how did individuals with a favored trait occurred?). Adaptation is commonly used in daily conversation. The students might have developed a model of explanation when they were interacting with other people. For that reason, the student would be familiar with Adaptation and consistently use their existing model even when they were challenged by different contexts and other competitive models. On the contrary, Change in a Trait is a concept in textbook which is alien to them. The students, who may or may not have any models of the concept, might have judged the model, looked at the information available and chosen the model most logically and reasonable to explain the concept in that particular contexts.

A significant number of students used the model of Ecological Species Concept (ESC) in Proteceae, Galapagos tortoises and Canary Island lizards by 32, 27, and 22 percent respectively. This model asserts that a species as a set of organisms exploits a single niche. The individuals of the same species have common ecological requirements; food source and habitat. A large number of students used the model of ESC in three contexts because the contexts are very similar, especially Galapagos tortoises and Canary island lizards. In these two contexts, the organisms live and are distributed in an archipelago in which the climatic, geographical, and ecological conditions are very similar. The students might have transferred the model of ESC from one context to the other.

In summary, the majority of students had conceptual difficulties on the fundamental concepts of evolution. The concepts of genetic variation and adaptation, in a particular, the students preferred to use non-scientific models in almost contexts. As for other concepts, although the scientific model is the most common model in all contexts, the percentage of the combination of non-scientific models in some contexts is higher that that of the scientific concepts.

Table 4.1 The Percentages of Students Using Models of Evolution to Explain a Fundamental Concept of Evolution in Varied Contexts

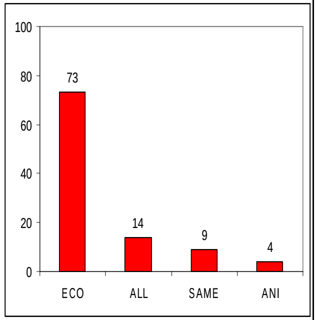
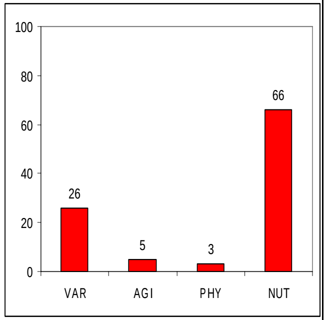
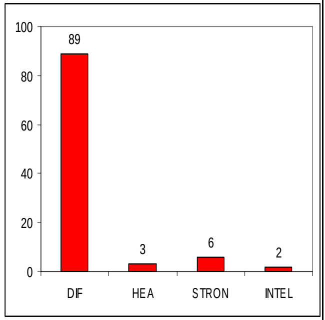
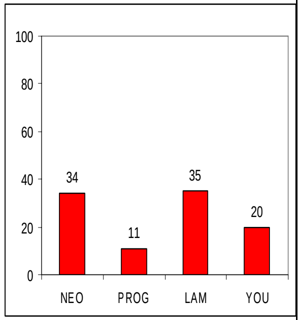
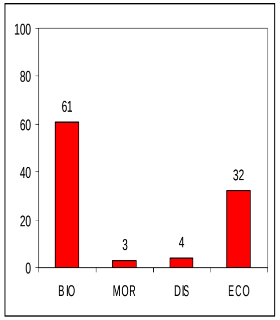
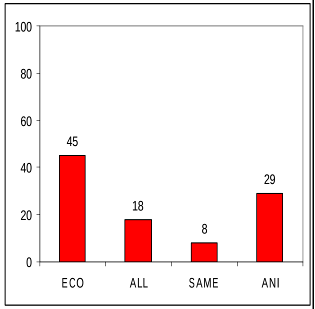
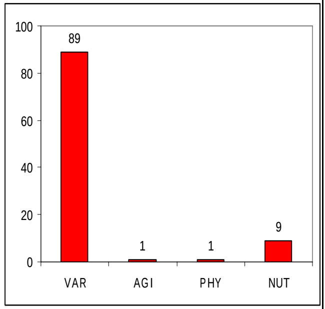
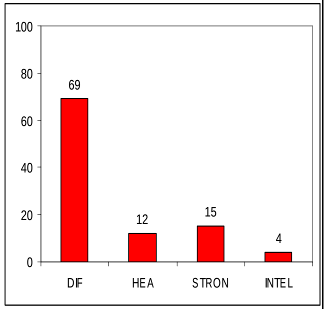
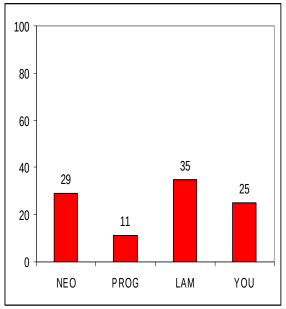
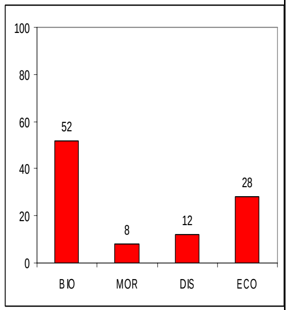
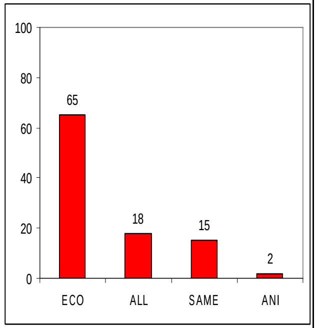
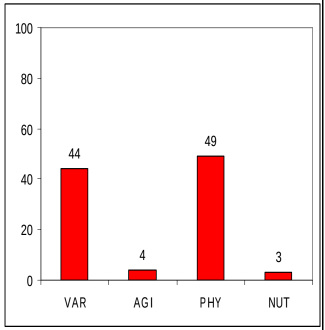
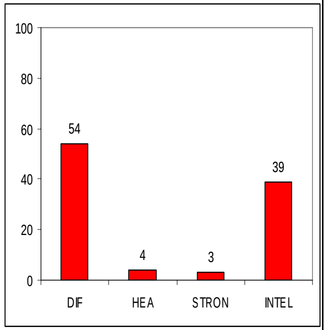
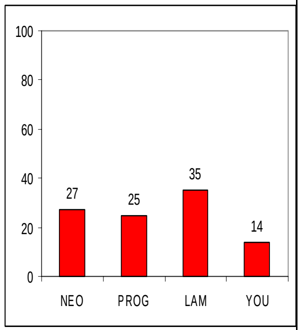
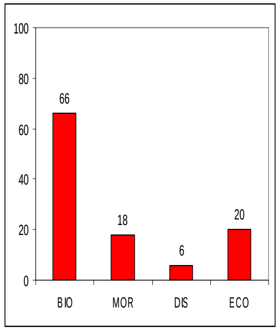
Concepts / Contexts	Population	Genetic Variation	Fitness	Adaptation	Species
Proteceae					
Galapagos tortoises					
Black Robin					

Table 4.1 (Cont'd)

<table>
<tr><th>Concepts / Contexts</th><th>Population</th><th>Genetic Variation</th><th>Fitness</th><th>Adaptation</th><th>Species</th></tr>
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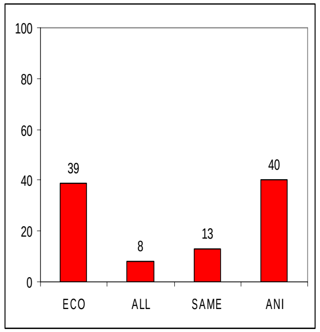
<td>
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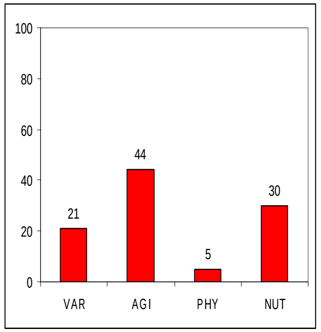
<td>
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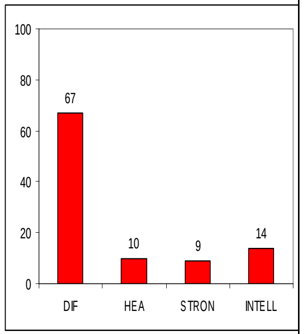
<td>
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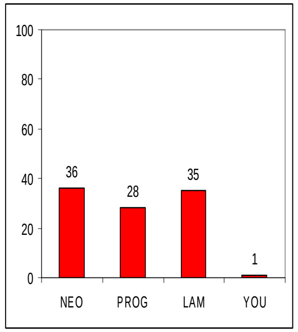
<td>
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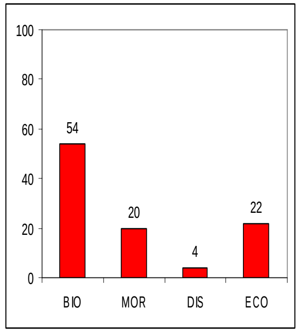
<td>
</td>
</tr>
</table>

Population

ECO (Scientific Model) = population is a geographically localized group of the same species which is capable of interbreeding.

ALL = Population is a group of everything; living, non-living or a combination.

SAME = population is a group of organisms in the same species.

ANI: population is animals only

Genetic Variation

VAR (Scientific Model) = variation is the difference by genetic material acquired by each individual.

AGI = variation is the difference by aging.

PHY = variation is the difference by outside agents such as decorating, shaping, pruning, repotting, and pinching.

NUT = variation is the difference by diet and exercise.

Adaptation

NEO (Scientific model) = a population phenomenon, whereby the population as a whole changes over many generations through the action of natural selection.

PROG = Individuals alter a trait from the originally created one.

LAM = Gradual changes in the traits themselves, viewing traits as improving or deteriorating from one generation to the next. The changes occur during the organism' s lifespan.

YOU = The organism do not adapt themselves. All of them always have the best and most suitable structure designed by nature.

Fitness

DIF (Scientific Model) = the relative ability of an organism to survive and to leave offspring that can survive and leave offspring.

HEA = being healthiest and having longest life span.

STRON = being strongest and biggest.

Intel = being most intelligence.

Species

BIO = An interbreeding, or potentially interbreeding, group of populations reproductively isolated from other groups.

MOR = Species are the group of organisms that are morphologically similar.

DIS = Species are the group of organisms are distributed in the same geographical area.

ECO = A group of organism that has the same environmental requirements.

Student Understanding of Evolutionary Process

Result

In this section, the percentages of students choosing scientific and non-scientific models of evolutionary process chosen by students are computed and described. The concepts measured in EDT include Origin of Variation, Role of Variation; Change in a Trait, Role of Environment, and Speciation and those in Evolution Fundamental Concept Test are Population, Genetic Variation, Fitness, Adaptation and Species. This section also examines the understanding of an evolutionary concept probed by varied contexts. The data used in the analysis is taken from the percentages of students choosing a particular model to explain an evolutionary concept in varied contexts of question as shown in Table 4.2 by columns.

Origin of variation

The most common models to explain the concept of origin of variation are Progressive Creationism and Lamarckism. Progressive Creationism is the most common model in the contexts of bentgrass, moth, and *E. coli* by 61, 75, and 57 percent of students respectively. Lamarckism is the most common model in finch by 74 %. In guppy, Progressive Creationism, Lamarckism, and Creationism (young earth) are the most common model by nearly the same percentages; 29, 30 and 31 percent. The majority of students preferred non-scientific model to the scientific model in origin of variation.

Role of variation

The most common models used to explain role of variation is Neo-Darwinism the scientific model; 61 % in bentgrass, 47 % in moth, 39 % in guppy, 84 % in *E. coli* and 72 % in finch. Although Neo-Darwinism is the most common model in moth and guppy, the percentages of student using non-scientific models is higher than that of scientific model holder. In guppy, for example, the combination of the percentages of non-scientific models is 61 %, nearly 2 times higher than that of the scientific models.

Change in a trait

The common models of change in a trait are varied compared to origin of variation and role of variation. Lamarckism, by 47 percent of students, is the most common model in bentgrass. Progressive Creationism is the most common model in moth and guppy by 56 and 37 % respectively. In guppy, Neo-Darwinism is also the most model by the same percentage as that of Progressive Creationism (37 %). Neodarwinism is the most common model in *E. coli* and finch by 41 and 56 percent respectively. The percentages of non scientific model in these two contexts are obviously noteworthy; 39 % of Lamarckism in *E. coli* and 32 % of Progressive Creationism

Role of environment

Neo-Darwinism is the most common model in all contexts except *E. coli*. In *E. coli*, the majority of students (44%) chose Lamarckism. The percentages of student choosing Neo-Darwinism in the other context is higher than 50 percent; 57 % in bentgrass, 65 % in moth, 82 % in guppy, and 62 % in finch.

Speciation

Lamarckism and Neo-Darwinism are the two most common models chosen by student to explain the concept of speciation. Lamarckism is the most common model in bentgrass and *E. coli* by 37 and 46 percent respectively. Neo-Darwinism is the most common model in the rest contexts; 70 % in moth, 43 % in guppy, and 65 % in finch. In guppy, however, the percentage of a combination of non-scientific models is quite higher than that of scientific model (57%).

Discussion

The majority of students did not use Neo-Darwinism, the scientific model, to explain the three concepts of evolutionary process; origin of variation, change in a trait, and speciation. Historical models were consistently used to explain these concepts in as the most common model varied contexts: Progressive Creationism and Lamarckism in origin of variation; Lamarckism and Progressive Creationism in change in a trait; and Lamarckism in speciation. The use of Lamarckism in origin of variation is consistent with the findings of Brumby (1984); Bishop and Anderson (1990); Greene (1990); Settlage (1994); Anderson et al. (2002); and Moore et al. (2002). These studies indicated that the students explained the origin of variation as the result of responding to an environment. Random mutation and gene recombination as sources of variation were missed out. The students may have not understood mutation and gene recombination and seen how these two sources generated genetic variation. After instruction, students could address the appearance of genetic variation within a population and its role in evolutionary process. However, they could not explain the origin of variation. This might stem from a restriction in cognitive development. Settlage (1994) explained that the concepts of the appearance of variation and role variation appeared within a Zone of Proximal Development (ZPD) of a great number of students in contrast to the concept of the origin of variation or random mutation which appear within a ZPD of a few of the students. "ZPD is the region between the ability of a child to learn a concept independently and the potential for learning a concept when the child's efforts are supported by someone with a fuller understanding, such as teacher or peer coach" (Wertsch, 1985 cited in Settlage, 1994: 456).

The use of Lamarckism in change in a trait confirms the findings of Deadman and Kelly (1978); Brumby (1984); Clough and Robinson (1985); Bloom (1989); Bishop and Anderson (1990); Greene (1990); Settlage (1994); Bizzo (1994); Robinson (1994); and Anderson et al (2002). Bishop and Anderson (1990) found that a majority of students understood that the trait itself changed: it improved or deteriorated gradually during the organism's life span and this acquired trait was inherited by their offspring. This occurred in all members of the population over time. Greene explained that the students choosing Lamarckism understood that the environment did not generate anything but the trait of focus and the individuals with trait are not compared with any having the ancestral trait. These students did not make a logical connection between survival and death and the definition of traits as advantageous or disadvantageous, or did not mention survival or death.

The use of Lamarckism in explaining speciation in this study is in agreement with the findings of Deadman and Kelly (1978); Brumby (1984); Clough and Robinson, (1985); Bloom (1989); Bishop and Anderson (1990); Greene (1990); Settlage (1994); Bizzo (1994); Robinson (1994); and Anderson et al. (2002). The students explained that the interaction between the environment and organisms forms the new species. The new species, according to Lamarckism, is considered to be more complex and perfect than the original species. The use of Creationism (young earth) to explain Speciation confirms the findings of Downie and Barron (2000) that although a number of students accepted the occurrence of within-species evolutionary changes, some of them strongly rejected the origin of new species or speciation. They thought that all species were created at once in a very short period of time. The study supports the findings of Halldén (1988) that a significant number of students explained Speciation in a Species level. The original species mutated to the new species.

The use of Lamarckism and Creationism in Origin of Variation, Change in a Trait, and Speciation indicates that the students had an anthropomorphic and teleological view. This corresponds to the studies of Bloom (1989), Tamir and Zohar (1991), Robinson (1994) and Anderson et al. (2002). The students using Creationism based their explanation on a teleological view. They believed that all organisms were created and fixed. The organisms had no need to change because they were always suited to an environment. The organisms were designed to best fulfil their purposes.

The students using Lamarckism explained Change in a Trait and adaptation as an intentional process where the organisms played an active role in a change process. In Bentgrass, for example, the students explained that the plants could accumulate tolerant capacity gradually. This explanation is based on the anthropomorphic view because they thought that the plant could act like a human that they could consciously consider their need and respond to the environment properly. Passmore (2001) characterized that use of Lamarckism to explain evolutionary change as absolute, automatic, all-or-none or deterministic process; "they will survive", "they all reproduced" rather than in contingent and probabilistic language such as "they had a better chance", or "they were more likely to reproduce". The use of Lamarckism might be governed by the assertion in IPST textbook which is written in a way that could mislead the students. It states that: "Lamarck was in the right track but he could not find supportive evidence" (IPST, 1990: 85).

In different contexts, the students used different models to explain concepts of evolutionary process. This can be seen in the concepts of origin of variation, change in a trait, and speciation. The students preferred to use a particular model over others because the chosen model might better fit the context and seems to be more logically reasonable than others. To explain origin of variation, the students used Progressive Creationism as the most common model in bentgrass, moths, and *E. coli* while in other contexts, they used Lamarckism the most. In bentgrass, moths, and *E. coli*, the students used Progressive Creationism over other models because they might have thought that the organisms in these contexts have something in common so it should be explained in the same way. Bentgrass, moths and *E. coli* discontinuous traits: the organisms have two discrete characteristics. It might be easier and more logical to the students to explain that, without regarding the environment, the original type changed to new type internally. Consequently, there were two types of the organisms in the population. A significant number of students used Lamarckism in finches and guppies which have continuous traits; a variety of beak types and body color respectively. It might be easier to them to explain that such variety came from the interplay between the organisms and the heterogeneous environment. A variety of beak types resulted from the response to different kinds of food.

In change in a trait, the students used Lamarckism over other models in bentgrass and *E. coli* because both of organisms have similar traits, tolerant (resistant) capacity. It is more logical for the students to use Lamarckism to explain a change in this physiological and internal trait: the non–tolerant (resistant) form accumulated the capacity gradually over generations. In Bentgrass, peppered moth and Finches, a significant number of students used Progressive Creationism. They used this model to explain the change in physical traits, explaining that the change of this trait was the result of the evolution of types within species.

In Speciation, the students used Lamarckism over other models significantly in *E. coli* and Finches. To these students, the original species over generations became the new species with more complex and functional characteristics. It might be more reasonable and logical to them to explain that to handle specific kinds of food more efficiently; the new species of finches need to have more sophisticated beak types. In guppies, a significant number of students (28%) used Mutation to explain speciation. To this group of students, mutation gives rise a new species. This idea may be influenced by science fiction and documentaries in the media. In peppered moths, the students preferred Neo-Darwinism because this context facilitates this model. There are two geographically separated areas, industrial and rural, in which has differing predominate forms of the moth. Therefore, the students might have thought that in the future, there would be only one form of moth occupying each area. If these two populations were not in contact for a long time, the two populations would diverge and become separated species. From the information provided, Neo-Darwinism is the most logical model to explain speciation of Peppered Moths.

In almost contexts, the students did not apply any models consistently across all concepts of evolutionary process. In other words, they interchangeably used different models to explain evolutionary process. However, the results indicate that students used the same model by similar percentages to explain the related concepts of evolution. The application of models over these related concepts shows the logic of student understanding. The consistency of use of Neo-Darwinism in concepts of Role of Variation and Role of Environment of an evolutionary process is shown in all contexts. In this context of bentgrass, for example, the students used Neo-Darwinism to explain role of variation and role of environment by similar percentages because, according to Neo-Darwinism, the two concepts are closely related and are the basic assumptions of the model. Without either of them, the model would have not been complete and incoherent and it would have not provided a rational explanation to the students. The logic between the change and selection processes suggests that the students tried to fit the change and the selection processes into the whole rather that using each part independently. The students using Neo-Darwinism were aware of genetic variation within the population of Bentgrass; tolerant and non-tolerant forms. They thought that the proportions of the two heritable variants are determined by the environment, the presence of elevated level of copper. Although the majority of students used Neo-Darwinism in role of variation and role of environment, they did not this scientific model to explain change in a trait. To these students, change in a trait is a conceptual difficulty. They could not link the role of variation and role of environment to explain how a given trait changed over time. However, in finches, the majority of students used Neo-Darwinism to explain change in a trait together with role of variation and role of environment. Notably, this context was used in IPST textbook to illustrate the mechanism of Neo-Darwinism (IPST, 1990: 91). Some of the students may have recalled it in this test. They may have regarded Neo-Darwinism as the correct model because it was stated in the textbook. They may not fully understand the scientific model.

The logic of student understanding can be seen in the use of Lamarckism. In *E. coli*, Lamarckism was consistently used over the change in a trait, role of environment, and speciation by similar percentages, 39, 44, and 46 respectively. According to this model, the students explained that the guppies responded to the predators by reducing pigments in their cells gradually during their life span. They passed on this acquired trait to their offspring. By this process, the guppies would eventually become a new, more complex and advanced species. The three concepts can all be explained coherently by Lamarckism.

The use of Creationism (young earth) also shows the logic of student understanding. Creationism (young earth) is the only model used by the students consistently across all five concepts of evolutionary process. In Finches, the students used Creationism (young earth) to explain all concepts by the same percentage (4%). This shows that the students held this model strongly and used it consistently. To this group of students, the earth and living things did not change. Instead, they were created all at once in a short period of time and fixed. Even though the students accepted that there was variation within a population, they believed that the variation existed originally in the population. The students thought that the proportions of each variant were always constant. There was no reason for the living things to change that proportions and develop a new species because their existing state always fit best the environmental condition. Any changes were considered as being against the rule of nature and this would produce harmful effects to the original species.

This result confirms the findings of Greene (1990) that there is logic to student understanding. There is a structure of students' explanation which allows one to logically trace the origins of the misunderstandings, the assumptions of non-scientific models. He found that in Lamarckism, the students using the idea of acquired characteristics tended to use non-selection idea. The students did not make a logical connection between survival and death and the definitions of traits as advantageous or disadvantageous and their response did not mention survival or death.

In summary, the student used the same model to explain the concepts that were the assumptions of that model. Neo-Darwinism, for example, was used consistently in role of Variation, change in a trait and role of environment. To explain Change in a Trait in Neo-Darwinism sense, the students must already have used this model in Role of Variation and Role of Environment. Understanding of these two concepts will provide a condition for Change in a Trait. The use of models to explain evolutionary process within a context is logical and consistent.

Table 4.2 The Percentages of Students Using Models of Evolution to Explain Evolutionary Concepts in Varied Contexts

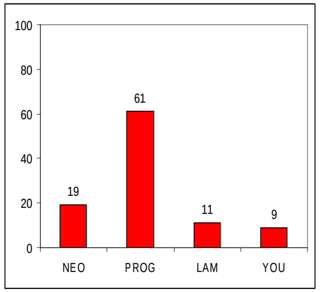
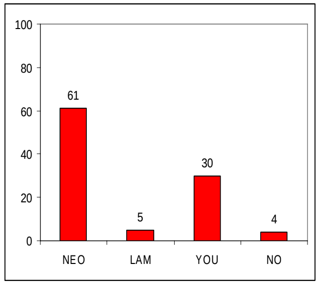
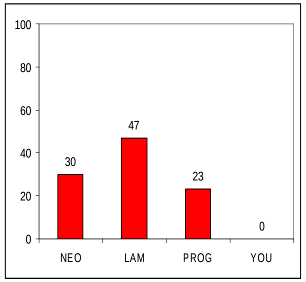
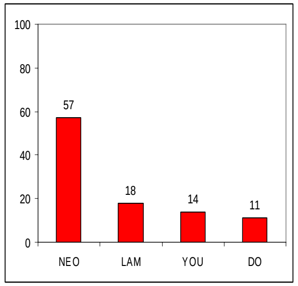
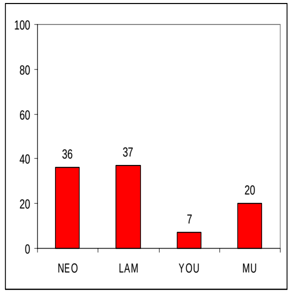
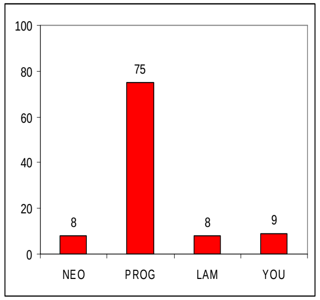
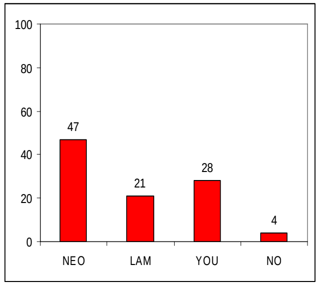
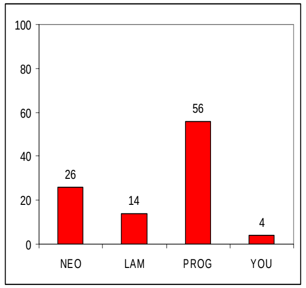
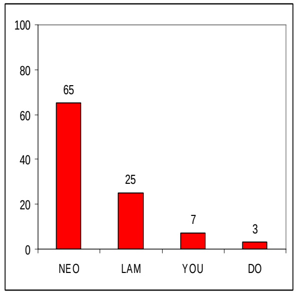
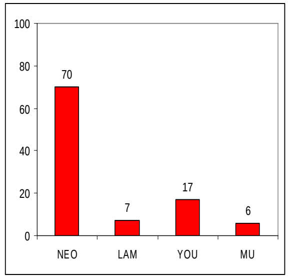
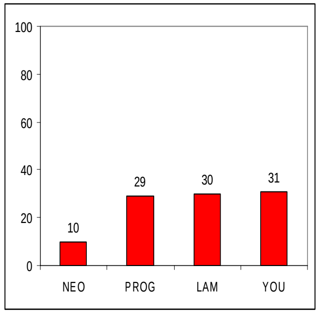
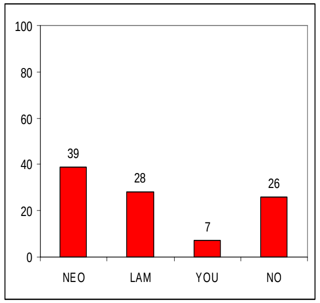
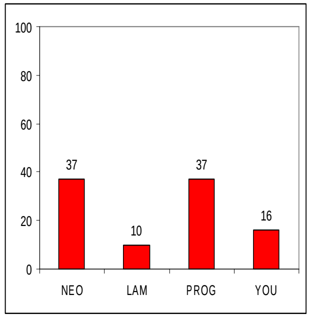
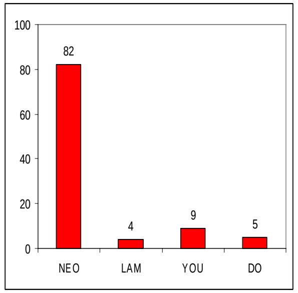
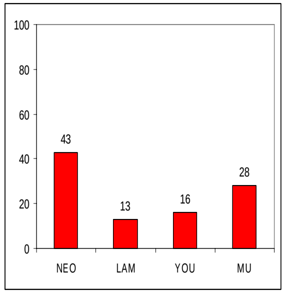
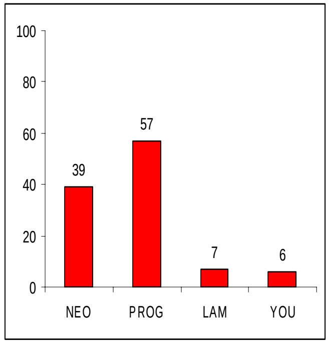
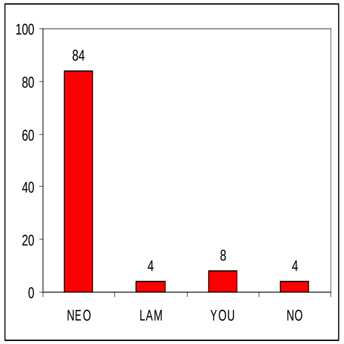
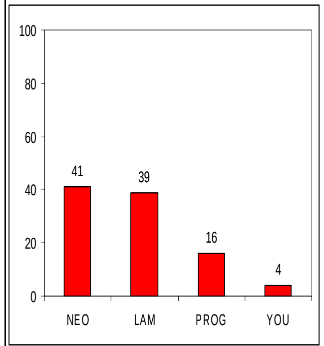
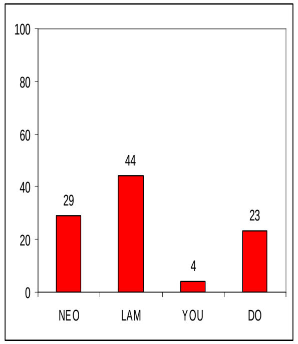
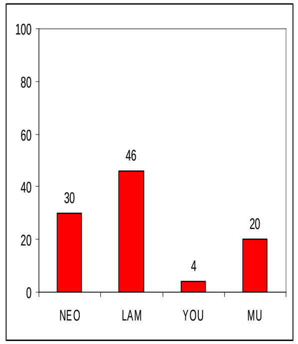
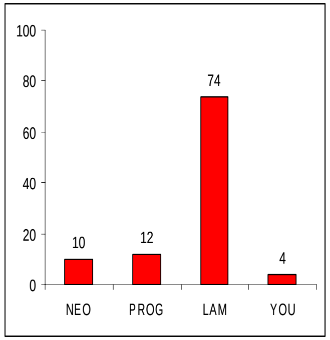
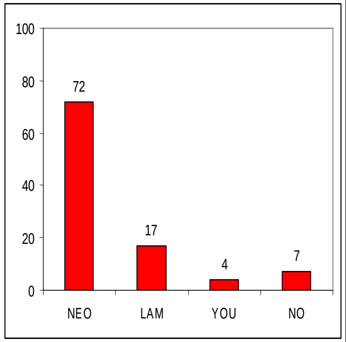
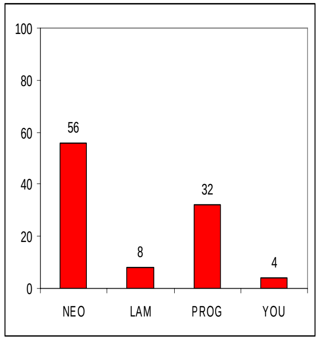
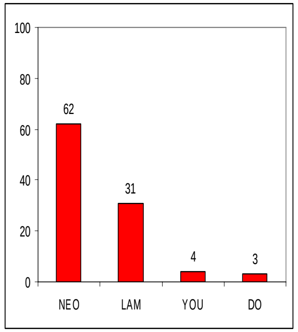
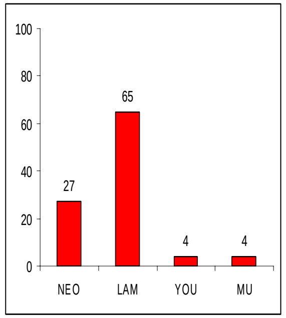
Concepts / Contexts	origin of variation	Role of variation	change in a trait	role of environment	speciation
Bentgrass					
Moth					
Guppy					

Table 4.2 (Cont'd)

Concepts / Contexts	origin of variation	role of variation	change in a trait	role of environment	speciation
E. coli					
Finch					

NEO = Neo-Darwinism LAM = Lamarckism PROG = Progressive Creationism YOU = Creationism (Young Earth) MU = Mutation
NO = Variation has no effect DO = Dominant/Recessive Gene

The summary of findings on student understanding of evolution process and its fundamental concepts

The students did not have scientific understanding of the fundamental concepts of evolutionary process especially in the concepts of genetic variation and adaptation. The students used non-scientific models to explain the two concepts in all contexts of question. As for student understanding of evolutionary process, the students did not use scientific model to explain almost concept components of evolutionary process; origin of variation, change in a trait and speciation. Like, the fundamental concepts, the students show inconsistence in use a model across different contexts. The students used different models to explain an evolutionary concept in a variety of contexts. They chose the model that best fit the information provided in the context.

Under a particular context, a particular model was more facilitated than other models. It seems to be more reasonable and logical than others. Remarkably, the students tended to use the same model in similar contexts; for example, to explain change in a trait, the students used Lamarckism the most in bentgrass and *E. coli* where physiological traits are the trait focused of both contexts; copper tolerant and antibiotic resistant capacity, respectively. It found that students' worldviews and their prior experience are the determining factors of selecting a particular model in a particular context. The students who held teleological worldview tend to use Creationism in their explanation while those holding anthropomorphic worldview tend to use Lamarckism. If a new context was similar to the one that had successfully been explained by a particular model, the students would transfer that model to the new context. Another point, the students did not consistently employ the same model over different concepts even when probed within the same context. In the bentgrass and *E. coli*, the majority of students used Lamarckism to explain change in a trait but Progressive Creationism in origin of variation.

Not only students' worldview and their prior experience are influential in the use of model of the students, but the instruction that these students had got before also partially affects their understanding of evolution. The following section describes the existing situation of teaching and learning evolution that these students had received and discussed how it affected on their learning.

Existing Situation of Teaching and Learning Evolution in 2002

Evolution education in transition: this study (2001-2005)

This phase of study focuses on the situation of teaching and learning evolution in academic year 2003, the transition between Upper Secondary Education Curriculum (1981, revised in 1990) and National Basic Education Curriculum (2001) reflected by 253 Grade 12 students and their biology teachers from three school in Bangkok and Nontaburi in academic year 2003. The teachers were in-depth interviewed by the interview schedule on the existing situation of teaching and learning evolution in terms of curriculum, textbook, teaching methods, instructional media and materials, and assessment. The teachers were also asked about how they prepared for teaching evolution under a school-based curriculum that would be implemented in the following years according to National Basic Education Curriculum 2001. As for the students, the teachers were explored their opinion on the same issues for the sake of data triangulation by Current Situation of Teaching Evolution (CSTE) questionnaire. Thirty six percent of students were male, 64 percent female. They were 17 -18 years olds.

All three teachers had more than 10 years of teaching experience in evolution. The teachers gained a degree in biology or biology education. They enrolled in various biology courses such as ecology, genetics, microbiology, botany and zoology. There were no coursework in evolution and biodiversity in a university level at that time. Evolution was a small topic in Introductory Biology. When came to teach this topic, the teachers had to study it all over again. IPST teacher manual was their primary source of learning evolution. The teachers had at least 16 periods of teaching workload per week. They taught Grade 12 biology and General Science. They were developing a school based curriculum as well as the curriculum materials and preparing document for external quality assurance.

Curriculum and Textbook

All teachers, Karnika, Sarapee, and Soyfah, use Upper Secondary Education Curriculum 1981 (revised in 1990) as a framework of teaching Grade 12 biology. In this curriculum, there were genetics and evolution in Grade 12 Biology. Karnika and Sarapee used Grade 12 Biology textbook as a primary source of evolution (IPST, 1990). This coincides with the response from the students. The textbook was the most common source of learning evolution reported by 95.25 percent of students. Less than 5 percent of students used internet, encyclopedia, and museum. Unlike the two teachers, Soyfah recommended a variety of textbooks to the students. She thought that although IPST textbook was easy to read and follow and informative, its presentation was unattractive because there were no hands on activities, examples, and illustrations in the textbook. Soyfah had developed her own activities and instructional materials to capture students' attention and participation, for example, debating on theories of evolution, making a fossil, doing a report on a particular topic and classroom presentation.

> "I think IPST textbook is very boring. The examples given don't help me understand the concept any better. Some confused me especially those of co-evolution and application of evolution. There aren't any activities in the textbook. I have to develop the activities on my own or adapt those of Physical and Biology Sciences (for the students in Social and Humanistic Program) to make the lessons more interesting. For short, for years, I have not involved with IPST materials", Soyfah said (interviewed on July 23, 2004)

When asked how the teacher prepared teaching evolution for school based curriculum, all teachers said they would use the former curriculum as the guidelines for the school based curriculum. They would continue using their current teaching methods, instructional materials, assessments and textbook for the new curriculum. Karnika said that her school based curriculum would not be so much different from the former curriculum and what she had been practicing. All teachers understood that there was nothing new in National Science Content in terms of objectives, scope and organization of evolution, suggested teaching strategies, and assessment. The school based curriculum could be replicated the former curriculum but there should be an emphasis on student-centered approach in teaching science.

Teaching methods

Karnika and Sarapee used lecturing and assigning students to do a report and have a classroom presentation in all topics of evolution. "Our Thai students as you know get prefer listening to the teacher. They don't want to think or answer. I admit that I get used to this method. It can make them understand science concepts", Karnika said in the interview. This is consistent with student opinion. Between 65 to 75 percent of student thought that their teachers gave a lecture for all topics of evolution. Twenty four to 35 percent of students reported that the teachers a particular topic of evolution to them to do a report and have a classroom presentation. Twenty five to 40 percent of students reported that the teachers had asked them to study topics of evolution on their own. Less than 18 percent of students reported that they participated in a group or whole class discussion. Less than 7 percent of students reported that they had engaged in hands on activities (Table 4.3).

Table 4.3 Teachers' Teaching Methods for Evolutionary Topics Reflected by the Students (%, N = 253)

Topics / Methods	Theories of Evolution	Evidence of evolution	H-W principle	Natural Selection	Application of evolution	Speciation	Human Evolution
Hands-on activities	3.95	3.16	5.53	6.71	3.16	3.55	3.16
Report presentation	35.17	35.57	26.87	30.03	24.11	28.06	35.17
Discussion	13.83	13.83	12.25	14.22	12.64	14.62	17.39
Self Study	35.96	33.59	29.64	32.80	25.29	26.08	39.92
Lecturing	73.12	69.56	66.07	68.77	66.00	66.00	67.19

The students found the passive learning unhelpful and boring. They wanted the teachers to explain them on the concepts as well as have an opportunity to do some hands on activities.

> "Doing and presenting a report is too much and so boring. I don't want to listen to them (other students reporting) anymore. I did not understand what they said. I don't know where it was important, not important, and how. I would like to know what might be in the exam, what might not. I can't stand with this. It happens every period. I want her to teach more. " said Malinee, a Karnika's student (wrote in CSTE).

Soyfah was the only teacher who had already developed some new activities. She used debating to teach theories of evolution. She reasoned that in those days, she had used lecturing for this topic but it made her and students bored. In addition when considered the concept, theory of evolution was still an issue. There were a number of theories proposed in the scientific community. She said that if she had told the student that Darwinism was the correct model, the students would have accepted, no doubt, because the teacher told them.

However, they may not have had an insight into or really believed in the theory. Nor did they appreciate nature of scientific knowledge.

> “Dividing them into 2 debating groups, Darwinism and Lamarckism and encourage them to argue their ideas would help them develop understanding of the two theories. To be able to defense their ideas, the students are supposed to study their theory very well. They must be able to identify the basic assumptions of the theory and distinguish between Lamarckism and Darwinism. This activity, said Soyfah (Interviewed on July 23, 2004).

All teachers did not review evolutionary related concepts that students had studied from previous units such as allele, genotype, genetic variation, meiosis, population, and mutation. The teachers reasoned that they did not have time to do so. They expected that students could still remember these concepts, especially genetics concepts because they had just learnt them in Genetics, the most previous unit. One teacher said that she had not taught biodiversity in Evolution Unit because she had taught in Taxonomy in Grade 10. The teachers did not integrate evolution and genetics and biodiversity.

Assessment

Karnika assessed student learning from test performance and their participation in classroom. Sarapee and Soyfah took into consideration multiple sources of data to assess student understanding for example, worksheet, portfolio, test performance, classroom participation, concept mapping. They had done the assessment both during and in the end of the course.

Problems about Teaching and Learning Evolution

Conceptual difficulty

All teachers thought that the most difficult topic in evolution was Hardy-Weinberg principle because it involved genetics and mathematics. "To work out allele and genotypic frequencies, the students must already understand the concepts of allele, genotype, and frequency", said Sarapee. Hardy-Weinberg principle was also the concept that Karnika was unclear and unconfident to explain to students. She did not know when and how she should start discussing this concept. She admitted that she could not make a connection between Hardy-Weinberg principle and other related concepts such as allele frequency, genotypic frequency, gene pool, natural selection. Sarapee said that her students could not explain the process of natural selection. Soyfah also found that her students could explain the sources of genetic variability and the change in allele and genotypic frequencies. When asked the students, however, the most difficult topic of evolution was not Hardy-Weinberg principle as most of their teachers thought. To them, 46 percent (table 4.4), the application of theory of evolution was the concept they most had trouble to deal with. They did not know how to apply Darwinism to explain the natural phenomena. The students need the teachers to give them more example of using Darwinism to explain evolutionary phenomena as one student said:

> "I want her to give me some more examples of application of evolutionary theories. I think we understand theories but don't know how to apply it especially for real situations. Another thing that I wonder is why I have to study Hardy-Weinberg Principle. It seems to me it suddenly pop up in the lesson. I don't khow how it is related to other topics of evolution" said Sutichai, a Sarapee's student (in CSTE).

Table 4.4 The Percentages of Students Choosing the Topics of Evolution Which They Found Most Difficult to Understand

Topics of Evolution	Percentage
The Application of Theory of Evolution	46.64
Speciation	44.26
Hardy – Weinberg's Law	36.75
Theories of Evolution	33.59
Factor Affecting Allele Frequency	30.80
Natural Selection	27.27
Human Evolution	26.08
Evidence of Evolution	21.34

Low attention

Karnika's and Sarapee's students gave low attention to the lessons. Karnika said that the student from high ability classroom did not give her cooperation in doing any assignment. In classroom, these students often did other work. Some of them were absent in the periods of evolution. Soyfah's students, on the contrary, participate in the activities very actively. She said that the students had changed their behaviors in a desired way after introducing the new teaching strategies.

Entrance Examination

All teachers explained that University Entrance Examination influenced teaching science in a high school level. They thought that teaching must be based on the tested content to get students best prepared for this highly competitive examination. Karnika said that evolution has very low proportion in the test compared to other topics of biology. The calculation of allele and genotypic frequencies and human evolution were the most common evolutionary concepts in the test. Genetics concepts were found much more common than those of evolution. By this reason, the instruction of Grade 12 (the second semester), was spent entirely on genetics unit, although the proportion of genetics and evolution in IPST textbook were even. Karnika had spent less than 5 periods for Evolution Unit, 7 periods less than that suggested in the textbook. She thought that evolution was not difficult. The students could read it from the textbook and make understanding by themselves. Teaching in classroom should just review the key ideas.

> "Putting evolution in the last chapter of the textbook, in my opinion, is a good idea because it is not so difficult. There are a few concepts to study. The students could study on their own, no problems. I think they like genetics unit the most but feel bored and sleepy on the evolution unit", said Karnika (Interviewed on July 19, 2004).

Teacher and student need

All teachers need to know teaching method for evolution and learning activities that could attract students' attention. They expected the activities to be more hands on, cooperative and challenging. They also wanted to know a variety of assessment techniques. The teachers, in addition, wanted to know about the cutting edge of evolutionary biology, know more examples and learning resources. As for students, they wanted a textbook to have more examples of evolutionary concepts. It would help them understand the concepts better. They also wanted the textbook to look more attractive including more colored pictures. The textbook should be written more logically and coherently. It should be easy to follow so they could study by themselves.

In textbook, there should be a link between topics of evolution. The students suggested the textbook to have a concept map of a whole unit in the front page. The textbook should refer to the concept map when introducing any topic to remind them what they would be up to. They wanted to be suggested for learning resources of evolution that they could study further on their own. The students wanted the teachers to use more instructional media. They requested, particularly, to watch a documentary about evolution. The students wanted to be more involved in learning evolution. They wanted to participate in hands on, thoughtful, and challenging activities and work in group such as doing an experiment, field trip, playing a game.

The relationship between teaching practice and student understanding of evolution

The instruction might have had an partial affect on student understanding of evolution. From the second survey, the teachers preferred to use lecturing and assigning students to do a report and have a class presentation to teach all topics of evolution rather than having a discussion or providing constructive learning opportunities to the students so they can actively engage in and come up with the ideas by themselves. The teaching style that the teacher had been using do not facilitate the student understanding, analytical and critical thinking. It, instead, calls for facts and memorization. It doesn't help student clarify and verify their existing understanding. Nor did it show them the strengths and the weaknesses of each model. The use of the scientific model was also not expanded to various evolutionary situations. As the result, the students still preferred non-scientific model to explain evolutionary process and inconsistently applied the models in varying concepts even after the instruction. It means they had not decided yet which model was right or wrong.

The results on student understanding of the fundamental concepts of evolutionary process imply that the teachers might not have made a link between related genetics concepts of Genetics Unit, the previous chapter and the process of natural selection of Evolution Unit. The strong understanding of genetics is essential to understand the evolutionary process. The students were expected to understand the concept of genetic variation because they had been taught it in the previous chapter, Genetic Unit. However, the test results indicate that the students still held the non-scientific model of this concept and could not explain evolutionary process, the target concept scientifically. The teacher might not have reviewed or referred to this concept in Evolution Unit so the students could not establish the connection of the related concepts.

Not only this teaching style; transmission of knowledge and fragmented instruction, could not enhance scientific understating of evolution to the students and help them make a connection between all evolutionary related concepts, but it also could not attract students' attention to the lessons. The majority of students reported that they dislike doing a report and having a class presentation. They thought that it happened too often. It was boring, unchallenging and not stimulating their thinking. They called for a new teaching style that allowed them more to actively involve in thoughtful, hands-on and collaborative works.

Implications of Survey Result for Intervention Design

The findings from the exploratory phase have implications for teaching evolution. The survey on student understanding of evolution indicated that the students had difficulty in the understanding some concept components of evolutionary process; origin of variation, change in a trait, and speciation and the fundamental concepts. The survey on teachers' and students' opinions on existing situation of teaching and learning evolution reflects current teaching strategies on topics of evolution, the use of instructional media and materials, classroom and school contexts, problems and suggestions on teaching and learning evolution. These students' conceptual difficulty and teachers' and students' needs have implications for teaching evolution as follows.

1. The intervention should firstly discuss explanatory models in science and nature of scientific knowledge. How practicing scientists judge model should be also

discussed. The intervention should emphasize that the scientists do not ask whether a particular model is “right”. Rather, they ask whether a model is “acceptable” because it should explain, predict, and be consistent with other knowledge (Cartier, Rudolph, and Stewart, 2001).

2. The intervention should enhance student understanding of Neo-Darwinism and other historical models. Its activities should ask students to examine the models, find out their assumptions, compare the assumptions and evaluate each model. The activity should ask students to elaborate the understanding Neo-Darwinism by using the model to explain a variety of evolutionary changes.

3. In classroom environment, a variety of contexts should be used to explain evolutionary concepts so the student can 1) better understand the concept 2) expand their understanding and 3) see how the concepts are used and applied.

4. The intervention should address students’ prior knowledge of evolutionary process. The students already have models of explanation before they get into classroom. The intervention should build scientific understanding up from there.

5. The instrument should assess student understanding of evolution by appropriate questions. The assessor and teachers must consider the suitability of question and use a variety of contexts in order to get closer to the mental model of the students and use formative assess to enhance effective learning.

6. The intervention should briefly review the fundamental concepts of evolutionary process at the beginning of each lesson. These concepts include population, genetic variation, meiosis, mutation etc.

7. The intervention should present various concepts of evolutionary process in an integrated way and show how these concepts are interrelated. A concept map can

be used at the end of each lesson to point the relationship between the concepts in a whole evolutionary process.

In the next chapter, there will be a discussion on the design and development of Evolution Learning Unit, an intervention designed to promote scientific understanding of evolution for Thai students. The developments are guided by the findings from the exploratory phase of study. This means student conceptual difficulties, Thai teacher and student need on teaching and learning evolution, and classroom context explored in this chapter will be brought into consideration.

CHAPTER V

DEVELOPMENT OF EVOLUTION LEARNING UNIT

Introduction

This chapter discusses the design and development of Evolution Learning Unit (ELU), an intervention that aims to promote scientific understanding of evolution and improve teaching and learning evolution. The chapter starts with a number of guiding principles that ELU is based on. The unit takes into account the results of the survey on Thai student understanding of evolution and the current practice of teaching and learning conducted in the first phase of study in 2003-2004, social constructivism and socio-cultural perspective of learning, and recommended evolution teaching strategies from literature. The process of intervention design and development is then discussed. The process comprises need assessment, planning session with advisory committee, developing intervention material and pilot delivery and revision. The attention will then be paid on the content and its organization of ELU followed by the comparison of contents and activities between ELU and former curriculum. The reasons for selecting and organizing content of ELU are provided. At the end of the chapter, the content and the activity of each lesson are elaborated.

Guiding Principles

The development of Evolution Learning Unit (ELU) was guided by the following principles.

Thai student understanding of evolution

The survey on Thai student understanding of evolution as discussed in Chapter Four reveals that the students had difficulties in understanding evolutionary process. It found that the model most used by student to explain the evolution of given organism was Lamarckism. The choice of model was inconsistent. It depends on the context of questions. The students tended to apply same models to explain similar contexts while they preferred to use different models across different contexts. A number of students did not have sound understanding of the fundamental concepts of evolution such as genetic variation, fitness, and adaptations. To help students overcome such difficulties, Evolution Learning Unit (ELU) lets the students distinguish three models of evolution; Creationism, Lamarckism, and Darwinism and evaluate the models in terms of the explanatory power, predictability, and evidence. In addition, the students are encouraged to apply Darwinism to explain the evolutionary change in a variety of contexts. By this strategy, the students would see the problems of Creationism and Lamarckism while Darwinism, the accepted model, was strengthen and reinforced. ELU also briefly reviews the fundamental concepts of evolution, which are mostly genetics'. Without genuine understanding of these basics, students could not understand evolution (Clough and Robinson, 1985; Greene, 1990; and Anderson et al., 2002). To be able to understand Hardy-Weinberg Equilibrium, for example, the students need to have an insight into the concepts of allele, genotype, and population before.

Student and teacher needs on teaching and learning evolution

The survey on the practice of teaching and learning evolution in 2003 depicts the problems of existing situation of teaching evolution and the need of teachers and students on an alternative way of teaching and learning evolution. The students reported that the teachers used lecturing to teach all topics of evolution. The students found this teaching method boring and unattractive. The students wanted the new intervention to be more active and collaborative. They would like to engage with hands-on/minds-on activities. The students wanted the intervention to help them connect the diverse concepts of evolution. To meet these needs, the intervention contains a variety of hands-on/minds-on activities particularly for the abstract and process topics such as models of evolution, micro and macroevolutionary changes. In microevolutionary changes, for example, the students were asked to work in group to examine if there were any changes in allele frequencies over generations. This exercise can demonstrate Hardy-Weinberg Equilibrium effectively.

Social constructivism

The theory of learning employed in the intervention is social constructivism. Most of the activities encouraged students to work collaboratively to accomplish the task. By interacting with their peers, the students can reflect their own understanding and get immediate feedback from their friends. This process also gets them to the right track earlier than they could do alone. In-group, the students are more comfortable to express, defend their ideas and critique others'. For example, in the Hardy-Weinberg Equilibrium, the students were assigned to work in a group of 4-5. Each of them took different responsibilities: one randomly drew two buttons out of the box to be a pair of parents; another worked out all possible four offspring of a pair of parents; another student computed allele r frequency of all generation and plot graph. The students are asked to swap their responsibility with each other in each round. Everyone, therefore, has a contribution to the group. ELU was developed based on Thai classroom context including the number of students in each class, the physical environment of the classroom, student performance, classroom behavior, facilities and resources. Doing so would make implementation of ELU practical in a real setting. ELU is flexible: it opens the opportunity for the teachers to adapt the activities to fit in with their own classroom conditions.

Successful teaching strategies suggested by the previous study and local resource

A number of successful teaching strategies in developing scientific understanding of evolution were reviewed in Chapter Two. Three of these strategies were adapted and used in Evolution Learning Unit (ELU) including a modeling approach of Passmore et al. (2002) in Lesson Two: Models of Evolution; a counting button exercise in Lesson Four: Population at the Equilibrium of the department of genetics, Kasetsart University (2001); and evolution and classification of

Caminalcules of Grendon (2000). These activities were used with permission. Using local resources is another characteristic of ELU. In the topic, Evidence for Darwinism, the students are given information of many fossil sites in the northeastern part of Thailand. This activity makes students appreciate that Thailand is one of the great evolution source and evolution is in their daily life.

Unit Design and Development Process

The development of Evolution Learning Unit embraces orderly thinking of intervention development as following steps.

Needs assessment

Student understanding of evolutionary process and evolution fundamental concepts explored by EFCT and EDT respectively and the current practice of teaching and learning evolution survey by CSTE in the first phase of study in Academic year 2003 were brought into consideration in designing the intervention. The concepts of evolutionary process which students had faced difficulty to understand include origin of variation, change in a trait, and speciation. The difficult fundamental concepts for students are the concept of genetic variation, fitness, and adaptation. The conceptual difficulties were given closely attention in the intervention in selecting the teaching strategies to encounter. The teachers' and students' concerns on teaching and learning evolution raised by teachers and students were also considered such as a shortage of instructional materials, hands on activity, and learning resources.

Planning session

The researcher studied the guidelines of the development of school science program from the National Science Curriculum Standards (IPST, 2002) in terms of the scope of evolution for grade 12 biology, expected learning outcomes, the format of lesson plan, and the suggested learning and assessment strategies. This aimed to make the intervention align with the requirement of the standards. The researcher then drew up the first draft of the intervention and submitted the material to advisory committee for comments. The advisory committee had participated in the design and development throughout the development process. The committee was comprised of three experts: a lecturer from the faculty of science who specialized in the content of evolution; and two lecturers from the faculty of education who had expertise in curriculum planning and design, pedagogy, and assessment and evaluation. The researcher had set meetings with each expert and all of them at various stages in its development to discuss about overall expected intervention outcomes, outline of major content focus areas, organization of content, suggested instructional strategies for each content area, draft outline of intervention package including lesson plans, student manual, visual aids etc. The meeting took into account the results of the first phase of study, successful teaching strategies from literature, social constructivist learning theory and Thai classroom context.

Developing intervention material

Developing intervention material and the planning session were undertaken simultaneously. In this step, specific learning outcomes were finalized for each content area, instructional strategies for each learning objective were developed, and as a result, lesson plans, student manual, instructional media were developed to guide students to successfully meet the expected outcomes.

Pilot delivery and revision

The activities of the intervention were piloted with a group of students to validate the content, instructional strategies and estimate the appropriate time for each activity. Pilot study also informed the researcher if the lesson plans and the instructional materials complete enough to guide their effective use with students; were the instructions clear and complete; the visual aids enhance learner focus and retention, etc. The workshop was then set up for the biology teachers who would implement the intervention in the academic year 2004. It was held in November, 2004 at the Faculty of Education, Kasetsart University. The teachers participated in the workshop were all those in the first phase of the study. The advisory committee was also invited to join the workshop. In this workshop, the teachers were presented the research outcomes from the first phase of the study and the rationale for the intervention. The researchers discussed the guiding principles, content and learning activities, the organization of the intervention and timeline. The teachers were then called upon to provide feedback on lesson plans, instructional material, and assessment so that necessary improvements can be made based on input from experienced classroom teachers. In the end of the workshop, the researcher discussed data collection, his role as a researcher and a mentor during the implementation, and teachers' role and previewed weekly teacher support sessions during the implementation. The session with the teachers will be delineated in Chapter Six, Intervention Implementation and Evaluation Phase.

The completed intervention package

Once the intervention had been tried out and revised as necessary, the validated intervention contained all materials in order to deliver and distribute the intervention to its target audience. A completed package included all lesson plans in teacher manual, student manual and instructional material and visual aids.

Content of Evolution Learning Unit

Evolution Learning Unit (ELU) consists of seven lessons and takes twelve periods of fifty minutes, or one full-month (three periods per week) to complete. This duration is equal to that allowed in the former curriculum so the intervention can fit to what the teachers had currently practiced. The content of the unit covers Content Standard 1.2 of National Science Content Standards (IPST, 2002). Content Standard 1.2 for Grade Ten to Twelve Biology puts an emphasis on the relationship between genetics, biological evolution and biodiversity. The standard states that the students should be able to explain the process of heredity, the causes of genetic variability due to mutation and recombination of genes, and how biological evolution accounts for the diversity of species. The students are required to develop an understanding of natural selection as a scientific model to explain the great diversity of organisms.

Regard to the content and organization of content of evolution in ELU (table 5.1), the unit starts with the discussion on the development of models of evolution in Lesson One: Development of Models of Evolution. This lesson introduces the students the idea about the models in science. The students need to have this understanding before they study three main models of evolution in Lesson Two: Models of Evolution. In the second lesson, the students compare, evaluates the models of evolution, and apply the scientific model to explain evolutionary phenomena. In Lesson Three: Evidence for Darwinism, a number of evidence for the scientific model is discussed such as fossil, comparative anatomy, embryology, biogeography, and molecular biology. In lesson Four and Five: Population at the Equilibrium and Evolving Population, the students study microevolutionary change. The lesson elaborates Darwinism and Neo-Darwinism by discussing changes in the frequency within a population or a species of its alleles (alternative genes) and their effects on the form, or phenotype, of organisms that make up that population or species caused by a number of factors; natural selection, genetic drift, non-random mating, migration, and mutation. In Lesson Six and Seven: Speciation and Macroevolution, the student studies evolutionary change at or above the level of species. It means the splitting of a species into two or the change of a species over time into another and any changes that occur at higher levels, such as the evolution of new families, phyla or genera.

The content of ELU and its sequence is similar to those outlined in BIO 045, the state textbook of former science curriculum, Upper Secondary Education Curriculum 1981 (revised in 1990) (see table 5.1). However, Evolution Learning Unit rearranges the topics outlined BIO 045 textbook by putting all related topics of evolution in one more complete, intergrated topic. For example, the topics, What is

Biological Species Concept? and Origin of New Species are combined under the topic: Speciation of ELU as well as the topics of Evolution in the Changing World, Extinction and Conversation in BIO 045 were combined under the topic of Evidence for Darwinism in ELU. In BIO 045 textbook, the topic, “What is Biological Species Concept?” was placed before the Origin of New Species. The rearrangement reduces the number of topics (called lessons in ELU) from 12 topics in BIO 045 to 7 topics in ELU. This sequence might make student misunderstood that reproductive isolating mechanism that distinguishes one species from others according to Biological Species Concept (BSC) result in the origin of new species. In fact, the isolating mechanism is the consequence of speciation. When two populations of a same species accumulate genetic difference over a significant period of time, they could not interbreed anymore because they have gradually developed the isolating mechanism.

In addition, Evolution Learning Unit elaborates upon the process of speciation. Guided by Mayr’s theory proposed in 1963, the unit divides the process of speciation into three steps; genetic isolation, the accumulation of genetic difference between two populations and secondary contact. Presenting speciation through these three steps would not only give students insight into how a species get to diverge but also help them link the process of speciation to the concept of factors influencing allele frequency of a population that they had learnt in the topic, Evolving Population. To understand the second step of speciation, the accumulation of genetic differences, the students need to go over the factors affecting allele frequency of a population including natural selection, migration, mutation, non random mating and genetic drift. This strategy would show the students how various concepts of evolution can be connected in a meaningful way.

Evolution Learning Unit has some concepts in addition to that BIO 045 such as nature of scientific knowledge and constructing a phylogenetic tree. These concepts are complementary to the target concepts. From previous research (National Academy of Sciences, 1998; Rudolph and Stewart, 1998; Passmore and Stewart, 2002), the development of models of evolution can be used to enhance student understanding of the nature of scientific knowledge. Therefore, this was given attention in ELU. Nature of scientific knowledge is discussed after the students have gone through the development of thinking on the origin of living things. This is an example of integrating nature of science with teaching science. Likewise, constructing a phylogenetic tree was included in the topic of Macroevolution because it would help student understand macroevolutionary change better because the phylogenetic tree is a graphic tool to show evolutionary interrelationships between taxa at or above the level of species that are believed to have common ancestry.

Table 5.1 A Comparison of Content and Its Organization between Evolution Unit in BIO 045 and Evolution Learning Unit

Evolution Unit in BIO 045 of Upper Secondary Education Curriculum 1981 (revised 1990)	Evolution Learning Unit
Topic 1: Theories of Evolution • Creationism • Lamarckism • Darwinism.	Topic 1*: Development of Models of Evolution • Types of scientific knowledge; fact, hypothesis, theory, law, and model. • Nature of scientific knowledge • Models of evolution; Creationism, • Lamarckism, Darwinism and Neodarwinism
Topic 2: Natural Selection • Bibliography of Darwin • Evidence used for proposing natural selection	Topic 2*: Models of Evolution • Comparison of Creationism, Lamarckism and Darwinism • Evaluation of the three models • Application of Natural Selection
Topic 3: Why Study Evolutionary Biology? • Application of Evolution for agriculture, medical science, conservation, etc. • Evolution as a unifying theme	Topic 3*: Evidence for Darwinism • Fossil • Comparative anatomy • Embryology • Biogeography • Molecular biology

* In ELU, it is called a lesson.

Table 5.1 (Cont'd)

Evolution Unit in BIO 045 of Upper Secondary Education Curriculum 1981 (revised 1990)	Evolution Learning Unit
Topic 4: Evidence for Evolution • Fossil • Comparative anatomy • Embryology • Biogeography • Molecular biology	Topic 4*: Population at the Equilibrium • Population • Allele and genotypic frequency • Hardy-Weinberg law and its assumptions
Topic 5: Mechanism for Evolution • Population • Allele and genotypic frequency • Hardy-Weinberg law and its assumptions • Factors changing allele frequency of a population; natural selection, mutation, migration, non-random mating and genetic drift.	Topic 5*: Evolving Population • Factors changing allele frequency of a population; natural selection, mutation, migration, non-random mating and genetic drift.
Topic 6: Evolution in the Developing World • Application of Evolution for agriculture, medical science, conservation, etc.	Topic 6*: Speciation • Biological Species Concept • Reproductive Isolating mechanism; pre and post-zygotic • Process of speciation; genetic isolation, accumulation of genetic differences, and secondary contact • Allopatric speciation • Sympatric speciation

* In ELU, it is called a lesson.

Table 5.1 (Cont'd)

Evolution Unit in BIO 045 of Upper Secondary Education Curriculum 1981 (revised 1990)	Evolution Learning Unit
Topic 7: What is Biological Species Concept? • Biological Species Concept • Reproductive Isolating mechanism; pre and post-zygotic Topic 8: Origin of New Species • Allopatric speciation • Sympatric speciation Topic 9: Human Evolution • The origin and development of humanity • Genus *Homo* and non hominids Topic 10: Extinction and Conservation • Impacts of commercial exploitation • Consequences of habitat loss • Affects of pollutants on reproductive competence • The links between biodiversity, conservation and social forces	Topic 7*: Macroevolution • Phylogenetic tree • Convergent evolution

* In ELU, it is called a lesson.

Activities of Evolution Learning Unit

The activities of Evolution Learning unit are different from those suggested in BIO 045. The common teaching strategies employed by BIO 045 are lecturing and discussion. ELU, on the contrary, employed a variety of hands on activities asking student to be more actively involved in the activities. The description of the activity of each lesson is briefly outlined below.

Lesson One: Development of Thinking on Origin of Living things

This lesson aims to introduce students to nature of scientific knowledge and link it to the case of evolutionary biology. The lesson takes one period (50 minute) to complete. The lesson starts with asking students to identify and justify the types of scientific knowledge of given statements. The criteria of classifying the knowledge as a fact, hypothesis, theory, model, and law are discussed. The students then play Scientist Thodsakun Game, which simulates a popular TV game show in Thailand in 2004, Thodaskun. In this game, the teacher shows ten pictures of the people involved with evolution such as Plato, Kant, Hutton, Lamarck, Darwin, etc. The pictures are ordered by the development of thinking. The students guess who in the picture is and tell about their ideas on the origin of living things. They consider how these various ideas related; which ideas correspond and which contradict. The teachers guide them to classify the ideas into three models; Creationism, Lamarckism and Darwinism. The characteristics of each model are then concluded.

Lesson Two: Models of Evolution

Lesson Two elaborates three models of evolution; Creationism, Lamarckism, and Darwinism. The activity in the lesson was originally developed by Passmore et al (2002). However, the researcher did not use the examples of living things of the original work because they are not domestic. Thai student might not know what they are. Therefore, they were replaced by plants and animals in mangrove forest that can be easily found in Thailand. The students listen to the portion of the original writings of Paley, Lamarck and Darwin. At the end of each writing, a number of questions about the writing are provided. The students are given tape scripts so they can go to the script if they need. After three writings are all presented, the students find the assumptions of each model and compare. The students are asked to evaluate the model and then apply Darwinism to explain the adaptation of plants and animals in mangrove forest.

Lesson Three: Evidence for Darwinism

Lesson three discusses the evidence for Darwinism. The evidence for descent with modification and natural selection includes fossil, comparative anatomy, embryology, and molecular biology. First, the students make fossil of given specimen such shell, leaves etc. They then see the fossil of Archaeopteryx and are asked to describe its structure. Archaeoptyryx shows evolutionary link between reptile and aves. The students move to another evidence, comparative anatomy by comparing the number of bone and their arrangement between frog and chicken's forelimb. The concepts of homologous and analogous structure are introduced afterward. The students observe the development of invertebrates' embryo. They are asked what stage of development they cannot be distinguished from each other. The last evidence, molecular biology, the students compare the percentage of matching DNA between human and other mammals.

Lesson Four: Population at the Equilibrium

This lesson reviews the fundamental concepts of Hardy-Weinberg Law such as population, phenotype, genotype, and allele by letting the students identify the terms from a number of statements. The teachers and the students then discuss the target concepts of the lesson; allele and genotypic frequencies, and cooperatively work out allele and genotypic frequencies of the given population. The students are assigned to solve three Hardy-Weinberg problems and compare the expected and computed allele frequency. The teacher explains why the expected and computed frequencies in a certain problem are similar and introduces the students to Hardy-Weinberg Law.

Lesson Five: Evolving Population

This lesson reviews Hardy-Weinberg Law by discussing the assumptions of the laws. The students then carry out by Counting Buttons, which is a simple hands-on activity to demonstrate Hardy Weinberg equilibrium. The Counting Bottons was initially created by the staffs of the Department of Genetics, Faculty of Science, Kasetsart University (Department of Genetics, Kasetsart University. 2001). The researcher adapted this activity slightly by reducing a number of generations from five to three so it can be done in two period time. The Counting Button lets the students keep watching the frequency of a particular allele of a given population over generations when all assumptions of the law are satisfied. Different types of button represent different genotypes: Black|Black button represents RR, Black| White, "Rr", and White|White, "rr". The students subsequently conduct another experiment to investigate the effect of natural selection on allele r frequency by removing White|White button out of each succeeding generation. The students plot graphs and compare r allele frequency over generations of the two populations that one, from the first experiment, undergo natural selection and another one, from the second experiment, did not.

Lesson Six: Speciation

The lesson is about speciation. First, a variety of species concepts are discussed; Biological Species Concept, Morphological Species Concept, and Ecological Species. Biological Species Concept, the most accepted species concepts in a community of practicing biologists and the reproductive isolating mechanism are discussed. The students then read situations and identify types of reproductive isolating mechanism. The concepts of allopatric and sympatric speciation are then introduced. The students are asked to explain the speciation of given species.

Lesson Seven: Macroevolution

Lesson seven is about macroevolution. The activity of this lesson is the Classification and Evolution of Caminalcules. Caminalcules are artificial animal created by a evolutionary biologist, Professor Joseph Camin of the University of Kansas (Gendron, 2000). The classification and evolution of Caminalcules was later introduced to science education community as a learning activity for macroevolution in high school level by Professor Robert Gendron of Indiana University of Pennsylvania. This activity aims to illustrate the principle of classification and some of the process of evolution. Gendron asserted that doing exercises with artificial organisms would let the students approach the task with no preconceived notion as to how the organism should be classified. In ELU, the researcher adapted the exercises to some extent after having a discussion with the biology teachers in the workshop in November 2004. The teachers thought that the original number of living and fossil species of Caminacules; 14 living and 57 fossil species, were too much. By this number would turn out a complicate phylogenetic tree which might be too difficult for their students to accomplish and take too much time. Therefore, the researcher cut the number of fossil from 14 living and 57 fossil species to 6 living species and 17 fossil species. The activity is divided into three exercises. The first exercise, the students examine the six living species and note the similarities and differences between them. They create a hierarchical classification of these species. In the second exercise, the students construct a phylogenetic tree based on the hierarchical classification in the first exercise. In last exercise, the students construct a phylogenetic tree of 23 Caminalcules including living and fossil species.

The concepts and the activities of all lessons are summarized in the table 5.2

Table 5.2 Concepts and Activities of Evolution Learning Unit

Lesson	Concepts	Activities	Duration (periods)
Lesson One: The Development of Models of Evolution	• Fact, Hypothesis, law, theory, and model • Nature of scientific knowledge • Creationism, Lamarckism, Darwinism, and Neodarwinism	• Identify types of scientific knowledge • Play Thodsakarn Games and classify ideas of people in the game about the origin of living things into Creationism, Lamarckism, and Darwinism	1
Lesson Two: Models of Evolution	• Creationism • Lamarckism • Darwinism • Neodarwinism	• Listen to the writings of Paley, Lamarck and Darwin • Find the assumptions of each model • Compare and evaluate the models • Use Darwinism to explain the adaptation of mangrove plants and animals	2

Table 5.2 (Cont'd)

Lesson	Concepts	Activities	Duration (periods)
Lesson Three: Evidence for Darwinism	• Fossil • Comparative anatomy: Homologous structure and Analogous structure • Embryology • Molecular biology	• Make a fossil and find the evolutionary linkage in the fossil of Archaeopteryx • Compare the forelimbs of a bird and a frog in terms of number and arrangement. • Compare the embryos of vertebrates and find the stage where the animals can/can not be distinguished • Compare the percentage of DNA matching between various species of mammal and human	2
Lesson Four: Population at the Equilibrium	• Allele frequency • Genotypic frequency • Hardy-Weinberg law	• Identify phenotype, genotype and allele from given statements • Work out allele and genotypic frequency in Hardy- Weinberg problems and examine the changes in frequency over generations.	1

Table 5.2 (Cont'd)

Lesson	Concepts	Activities	Duration (periods)
Lesson Five: Evolving Population	• Mutation • Selective mating • Genetic drift • Mutation • Migration	• Carry out counting buttons and work out allele and genotypic frequencies of a population over generation and examine the changes in frequency when the populations undergo and do not undergo natural selection.	2
Lesson Six: Speciation	• Biological Species Concepts • Isolating mechanisms; pre- post zygotic. • Allopatric speciation • Sympatric speciation	• Compare three definitions of species • Identify types of isolating mechanisms • Explain the speciation of given species	1
Lesson Seven: Macroevolution	• Phylogenetic tree • Anagenesis • Cladogenesis • Extinction	• Classify Carminacules • Make a phylogenetic tree of the Carminacules based on their morphology and fossils • Identify extinction from a phylogenetic tree	3

Summary of the Chapter

This chapter discussed the design and development of Evolution Learning Unit from the guiding principles that the unit are based on, the development process, and its content and activities. According to the standards, evolution is taught as a topic in compulsory Fundamental Biology for all students and an elective Integrated Advanced Biology course on its own called Evolution, Genetics and Biodiversity for the students in Science and Mathematics Program. Evolution Learning Unit (ELU) can serve both. The schools could adopt or adapt some part or the whole unit for all of those courses. In the next chapter, Chapter Six: Intervention Implementation and Evaluation, Evolution learning Unit were implemented in three schools; the other two research questions will be investigated: how biology teachers implement the invention in their classroom settings? And does the intervention enhance student scientific understanding of evolution?

CHAPTER VI

INTERVENTION IMPLEMENTATION AND EVALUATION

Introduction

This chapter discusses the implementation and evaluation of the Evolution Learning Unit (ELU). The chapter starts with a workshop set up to train the teachers to implementing ELU and to gather their input for further improvements to the Unit. The next section introduces the implementation of the intervention in three schools during the second semester of the 2004 academic year. Teacher profiles are also provided in this section and the implementation of the intervention is discussed separately for each school. There is an in-depth description of the school and classroom environments, and the nature of the students, for each school. Two research questions are posed and investigated for each school in the study. They ask how the teacher implemented the intervention in their own setting, and how this affected student understanding of evolution. To answer these research questions, a number of methods of data collection, comprising tests of student understanding, interviews, and classroom observation are employed.

Participants and Settings

Four teachers from three schools were involved in trialing the ELU in the second semester of the 2004 academic year. They had all participated in the first, exploratory phase of the study, as discussed in Chapter Four. All four schools have a long-term relationship with the Faculty of Education at Kasetsart University, as the schools provided field experience for pre-service science teachers in their final year of study. All the schools are large (2,500 – 3,000 students), but they differ in terms of facilities, student input, surroundings, and economic background. Pseudonyms were used for both the schools and the teachers in this study, to preserve their anonymity. In two of the three schools, there was only one teacher responsible for Grade 12 Biology. The other one school, Nanfah Vitthayalai, there were two.

All teachers were asked if they would like to implement the ELU in all their grade 12 Biology classes. Karnika, Soyfa, and Pinsuda wanted to use it in all their classes. They said it would be difficult and confusing to teach only some classes in this way. However, Sarapee did not want to employ the ELU in all her classes. She said that trying out the ELU in all classes was too much for her. She also believed that the average and low achievers would not react well to the intervention, predicting that they would not participate in any activities. Sarapee viewed this group of students as lazy and unenergetic, and preferred to use her own methods to teach them.

According to the National Basic Education Curriculum, by the beginning of the 2003 academic year, all secondary schools in Thailand had to begin implementing a new school-based curriculum in grades seven and ten. This would be extended to other grade levels as these students moved up in subsequent academic years. By the 2005 academic year, the school based curriculum was to have been implemented at all grade levels. However, in the academic year 2004, when this research was carried out, the schools in the study still employed the former curriculum, Upper Secondary Education Curriculum (Revised in 1990) and used Grade 12 Biology textbook (IPST, 1990). Nevertheless, all the schools had been designing learning activities and developing instructional material for the school-based curriculum, and these were to be implemented in the 2005 academic year. Thus, the ELU was trialed in the transition from the former national curriculum to a school-based curriculum.

Implementation of the ELU

Teachers play important role in developing student understanding of evolution (Bloom, 1989; Ruthledge and Warden, 2000). Each teacher will have her own way of teaching evolution, and this may have been developed over many years of classroom experience. This means that, in order to bring about significant changes in teaching practice, the teachers themselves need to understand and accept the rationale for such changes. This will require considerable reflection on current knowledge and practice in teaching a particular topic and on student learning outcomes (Shulman, 1987;

Loucks-Horsley,1996; Loucks-Horsley, et al.,1998). Teachers need to recognize the benefits of the intervention, ELU, because they will be making a considerable investment in time and effort in adapting their teaching to deliver this new material. They must also receive continuous support and encouragement, and feel themselves to be part of a team; here they can share their new experiences and receive help if they encounter any problems during implementation of the new teaching unit. A workshop and a series of teacher support meetings were set up to fulfill all of these requirements. The timing and focus of these workshops is summarized in table 6.1.

Table 6.1 Overview of Workshop Structure and Content

Topics of Discussion				
Before implementation	During implementation			
Workshop (26/Nov/2004)	Teacher Support Meeting I (8/Jan/2005)	Teacher Support Meeting II (15/Jan/2005)	Teacher Support Meeting III (22/Jan/2005)	Teacher Support Meeting IV (29/Jan/2005)
- Overview of research project and its findings on a) student understanding of evolution and b) current ways of teaching evolution - The development of ELU; guiding principles; evolution in Science Education Curriculum; Comparison of ELU and IPST (content and activities) - ELU material (teacher manual, student manual); Lesson plan (objectives, key ideas, teaching guidelines, assessment, instruction material) - Demonstration of Lesson Plan 1-7 - Roles of the researcher; relationships between teachers and the researcher; teacher responsibilities	- Reflect on their teaching (lessons 1 and 2) - Student response to content and activities - Teacher satisfaction with their teaching: whether they could teach on time and as planned. - Problems about teaching - Misconception (nature of scientific knowledge, model in science, models of evolution) - Preparation for the next lesson	- Reflect on their teaching (lesson 3) - Student response to content and activities - Teacher satisfaction on their teaching: whether they could teach on time and as planned. - Problems about teaching - Preparation for the next lesson	- Reflect on their teaching: (lessons 4 and 5) - Student response to content and activities - Teacher satisfaction on their teaching: whether they could teach on time and as planned. - Problems about teaching - Misconception (population genetics and H-W principle) - Preparation for the next lesson	- Reflect on their teaching (lessons 6 and 7) - Student response to content and activities - Teacher satisfaction on their teaching: whether they could teach on time and as planned. - Problems about teaching - Misconception - Evaluation of ELU (Overall)

Initial workshop

This workshop was set up to involve teachers in the development of the Evolution Learning Unit (ELU), and work with them in investigating ways to implement it. The feedback from the participating teachers was very important, as it was used for the evaluation and further improvement of the ELU. Two weeks before the workshop, the teachers were given ELU documents to read, so that they could prepare for the meeting. The workshop itself began (table 6.1) with a presentation on and discussion of the findings of the first phase of the study, Exploring Student Understanding of Evolution and the Existing Situation of Teaching and Learning Evolution, which had been conducted in 2003. This revealed student difficulties with understanding evolution, and also noted some problems with teaching and learning evolution when using the former curriculum (IPST, 1981 revised in 1990). The findings were presented in details in Chapter Four, Student Understanding of Evolution and Current situation of Teaching and Learning Evolution.

The Evolution Learning Unit was then introduced as an alternative way of teaching evolution, aligned with the current National Science Curriculum Standards (IPST, 2002). The researcher discussed how the intervention was developed, guiding principles underpinning the intervention and also compared the content and activities of the ELU and the former curriculum document. Next, the teachers were briefed how to put the seven lesson plans into practice, lesson by lesson by introducing the objectives of the lesson, key concepts, teaching guidelines, instructional material and assessment. They were then asked to comment and make suggestions on the lesson. It was emphasized to the teachers that they could adapt the intervention to fit their student need and classroom context. The negotiation between the researcher and the teachers was made in a 2-way interactive manner in order to establish a partnership between the researcher and the teachers. Finally, the researcher explained about his and the teachers' role during the implementation. The outcomes of this workshop are presented below.

Content

The content of the ELU (table 6.2) is organized into three consecutive themes: models of evolution, micro evolution and macro evolution, as the curriculum standards suggested. The unit starts with models of evolution, and elaborates on Neo-Darwinism as the scientific model for evolution. This is followed by evidence of descent with modification, and the mechanism of natural selection, in lesson plan three. Lessons four and five discuss the mechanisms of micro evolutionary change, and the last two lessons focus on speciation and macro evolution.

The teachers agreed that the content of the ELU covers all concepts of evolution in the National Science Curriculum Standards (IPST, 2002). They thought that the ELU provides integrated coverage of genetics, evolution, and biodiversity. The teachers also concurred that the unit put an emphasis on the nature of science. The first three lessons enhance student understanding about history and nature of science. The lessons emphasize that scientific explanations must be consistent with experimental and observational evidence about nature, i.e. they are evidence-based, and are capable of being tested. Therefore, all scientific knowledge is subject to change when new evidence becomes available.

Activities

The teachers thought that the ELU activities (table 6.2) would enhance student understanding of evolution. All lessons required group work (Bell, 1993; Tobin & Tippins, 1993; Duit and Treagust, 1998; Cobern and Aikenhead, 1998). The students were encouraged to work together in small collaborative groups in which individual students had the opportunity to describe objects and events, and to construct and test their explanations for these events. For example, in Lesson Two, “Models of Evolution”, the students were required to identify and justify their existing model by arguing from evidence, and to critically assess and challenge the scientific explanations of one another.

The teachers also felt that ELU activities would be interesting to students of all abilities because their students loved to do hands-on activities. Their students wanted to use a wide range of equipments, materials, supplies, and other resources for experimentation and direct investigation of phenomena. However, one teacher said ELU activities would work only for high achievers. She strongly believed that her average and low achievers would not be interested in the suggested lesson, nor would they cooperate in group activities. She argued this group of students had poor interest in class work and were unable to think logically. She insisted that she would implement the ELU only in her high ability classroom and would use her own methods for the other three classes that she taught.

The teachers were concerned about the time available for two activities: the "Counting Buttons" lab exercise, and constructing a phylogenetic tree of "Caminalcules" They were worried that the five periods, of fifty minutes each, allowed for these complex activities might not be sufficient (table 6.2). In "Caminacules", the teachers felt that there were too many species of Caminacules for the students to classify and place in a phylogeny. Their concerns with the "Counting Buttons" exercise centered on the amount of time it would take for the students to perform two lengthy simulations: in each experiment, the students would examine a change in allele frequency over five generations. To resolve these issues, the meeting agreed to simplify the activities, but also agreed that the students must be able to reach the same understanding of a concept as if they had learnt from the original version.

As a result, in the "Caminalcules" activity, the number of Caminacules was reduced from 14 living and 58 fossil species to 6 living and 17 fossil species, in order to simplify development of a phylogenetic tree. In the "Counting Buttons" exercise, the teachers would assign a group of students to do only one of the two experiments, and would ask all groups to share their results. It was hoped that this management technique would keep the lesson to its allocated time.

Materials

The teachers commented on the ELU materials, which include a teacher manual, student manual, and instructional media. The teachers thought the teacher manual was helpful for them. They thought that the content of each lesson plan was informative and a useful addition to the IPST textbook, and that the lesson plan set clear goals and expectations for students. Teaching and assessment strategies were consistent with the goals. The teaching guidelines were practical and flexible. They said that the lesson plans provided them a detailed, step-by-step description of how to implement the lesson and achieve lesson plan objectives. The teachers were informed that they could adjust the lesson to make it more suitable for their students' needs and the classroom context.

With regard to resources, the teachers felt that the ELU provided them with a broad range of instructional materials: worksheets, scientific apparatus, and instructional media, as well as specific tools for particular activities. These resources were generally ready to use and would capture student interest, although one teacher suggested that font sizes in some visual resources should be larger. The student manual also provided various sources of scientific information that students could access themselves, such as books, periodicals, and the website addresses of Internet sites. One teacher suggested that students should be assigned to use the Internet to search for information relevant to the concepts in every lesson. She argued that this would strengthen and extend ideas, and develop their searching skills.

Assessment

As for assessment, the teachers thought that the ELU included multiple assessment strategies: testing, questioning, task assessment, class presentation; and also suggested ways to gather data about student understanding. The teachers suggested there should be self-assessment items in the student manual, so that the students could reflect on their learning and how they had been taught. The meeting agreed to add a section called Student Voice in the end of each lesson in the student manual. In this section, the students were provided space to speak their mind on: 1) what they had learnt from the lesson; 2) what concepts they had not been clear about; and 3) problems that they had faced and suggestions. Student Voice was useful for the teachers. It would let them know how the students thought of their teaching, the concepts that they did not understand; so the teachers could adjust their teaching to meet their needs. This assessment is also useful for the researcher as it would be another source of data beside testing and interviewing and it could reflect on their learning and satisfaction on the intervention.

In summary, the teachers thought that the ELU was aligned with Thailand's National Science Curriculum Standards (IPST) in terms of content and teaching methods. Its content covered all concepts of evolution in the standards and was well organized. The unit had more hands-on activities than the IPST textbook, and these were interesting and motivating to students. The teachers understood all activities and thought they could implement the ELU in the classroom. However, they were concerned about the complexity of some activities, the time constraints, suitability for students of varying abilities and some technical aspects of the intervention.

Table 6.2 Concepts and Activities of the Evolution Learning Unit

Themes	Lesson / Duration	Concepts	Activities	Prerequisite concepts
Models of evolution	Lesson One: The Development of Models of Evolution (1 period)	• Fact, Hypothesis, law, theory, and model • Nature of scientific knowledge • Creationism, Lamarckism, Darwinism, and Neo-Darwinism	• Identify types of scientific knowledge • Play Thodsakarn Games and classify ideas of people in the game about the origin of living things into Creationism, Lamarckism, Darwinism and Neo-Darwinism	fact, hypothesis, law, theory
	Lesson Two: Models of Evolution (2 period)	• Creationism • Lamarckism • Darwinism • Neo-Darwinism	• Listen to the writings of Paley, Lamarck and Darwin • Find the assumptions of each model • Compare and evaluate the models • Use Darwinism to explain the adaptation of mangrove plants and animals	Model in science, genetic variation, origin of genetic variation, inheritance
	Lesson Three: Evidence for Darwinism (2 period)	• Fossil • Comparative anatomy: Homologous structure and Analogous structure • Embryology • Molecular biology	• Make a fossil and find the evolutionary linkage in the fossil of Archaeopteryx • Compare the forelimbs of a bird and a frog in terms of number and arrangement of parts. • Compare the embryos of vertebrates and find the stage where the animals can/can not be distinguished • Compare the percentage of DNA matching between various species of mammal and human	

Table 6.2 (Cont'd)

Themes	Lesson / Duration	Concepts	Activities	Prerequisites
Microevolution	Lesson Four: Populations at Genetic Equilibrium (1 period)	• Allele frequency • Genotypic frequency • Hardy-Weinberg law	• Identify phenotype, genotype and allele from given statements • Work out allele and genotypic frequency in Hardy- Weinberg problems and examine the changes in frequency over generations.	Population, allele and genotypic frequencies
	Lesson Five: Evolving Populations (2 period)	• Mutation • Natural selection • Selective mating • Genetic drift • Mutation • Migration	• Carry out "Counting buttons" and work out allele and genotypic frequencies of a population over generation; examine the changes in allele frequency when the populations undergo and do not undergo natural selection.	Natural selection, mutation, migration
Macroevolution	Lesson Six: speciation (1 period)	• Biological Species Concepts • Isolating mechanisms; pre- post zygotic. • Allopatric speciation • Sympatric speciation	• Compare and discuss three definitions of species • Identify types of isolating mechanisms • Discuss the modes of speciation; allopatric and sympatric speciation. • Explain the speciation of Galapagos finches and bread wheat	Factors influencing the change in allele frequency in a population
	Lesson Seven: Macroevolution (3 periods)	• Phylogenetic tree • Anagenesis • Cladogenesis • Extinction	• Classify Caminalcules • Make a phylogenetic tree of the living & extinct Caminalcules based on their morphology • Identify extinction from a phylogenetic tree and discuss why it happens.	Classification

Teacher Support Meetings

Teacher support sessions are the meetings held every Saturday morning in January 2004, during the implementation of the ELU (table 6.1). The objectives of the meetings were to provide support and encouragement to the teachers in implementing the unit. At ach meeting, the teachers were first asked to reflect on their teaching: whether they could do as they had planned, how the students responded to the ELU, the problems that they had faced in the classroom and the limitations of implementing the new curriculum materials. This would help the researcher provide genuine assistance to the teachers. The data from classroom observation were also shared with the teachers. However, the teachers were assured that the observations were not intended as an evaluation of their teaching, but as a way of identifying difficulties with implementing the ELU. The meeting discussed why a particular difficulty might have arisen and tried to reach the best solution to it. Teachers' apparent misconceptions about some concepts were also explored, as were those concepts that they found difficult to understand and explain to students.

Key findings from teachers support meetings

The input of the teachers to the teacher support meetings was categorized into 3 key findings; student response to the intervention, the difficulties of implementation, and limitations to the implementation of the ELU as follows.

Student response to the intervention

The teachers agreed that their students paid more attention to lessons and enjoyed doing the ELU activities. The student worksheets were clear: students understood the instructions and laboratory directions and could do the work accordingly. The teachers also said that the ELU enhanced the students understanding of the evolutionary process. After engaging in the activities, the students could explain the process of evolution and apply it to explain various evolutionary situations in the worksheets. Moreover, students of all abilities paid a lot of attention to the ELU activities. One teacher mentioned that the low-achieving students, who had not participated in any activities previously, changed their behavior in a positive way after she introduced the ELU activities. These students were very keen to learn. They kept asking her when they would do the hand-on activities again. The students were obsessed with the activities; they took part in earnest and collaboratively. This teacher's own attitudes toward this group of students changed considerably, and she felt very proud of their achievements.

> "To engage in the activity, my students have gained direct experience bringing them insight into the concepts. They were very happy to work in-group. They looked happy and lively. When somebody in the group got stuck, the rest could help him out. From my point of view, the ELU is successful because it could draw student attention. This has never happened to me before. I also have learnt a lot from implementing the ELU in terms of content and teaching strategies" (Karnika, a Grade 12 Biology teacher from Racha Pittayalai School)

However, one teacher found some students from her high ability class did not like to do the ELU activities. These students were worried about the entrance examination for university. They wanted the lessons to prepare them for the examinations, and wanted the teacher to be more focused on the entrance examination and the concepts that might be included in it. These students did the activities reluctantly and always went off task. This confirmed the findings of classroom observation in the first week of implementation. More than of fifty percent of students of this class had already met the requirement of the field they had applied for in the first round of university entrance examination held in October 2004 (the implementation in January 2005) while the rest of them were preparing themselves for the second time exam in April 2005. It found that both groups did not give much attention to the lesson. For example, when they were asked to listen to the writing of Paley, Lamarck and Darwin, many of them did other work and chatted. When asked to form a group to identify the assumptions, make a comparison, and evaluate the models, they were not cooperative. The teacher said that the students were always like this when asked to work in group to have a discussion or do a report or a classroom presentation. They loved to listen to the teacher, take note, and do exercises. She had faced this problem before. It was not the effect of the ELU. In the later weeks, from a classroom observation, they had changed their behavior positively especially when they did “Making a Fossil” and “Counting Buttons”. They were very keen and looked absorbed in doing the activities. They understood the lab directions and could run them on their own. They took very little time compared to other classes to complete the tasks as well as solving Population Genetics and Hardy-Weinberg problems.

Difficulties identified by teachers

Teacher Understanding of Content

The teachers experienced difficulties with the content material on evolution in three areas: linking the concept of the origins of variation with the process of natural selection, the application of Darwinism; and the relevance and the use of the Hardy-Weinberg Principle. Three of four teachers did not identify random mutation and gene recombination as the sources of individual variation, when they taught the mechanism of natural selection. The teachers understood this concept because they had taught it in Genetics, the previous unit of study. However, they were not consciously aware of the connection between this concept and natural selection. They did not understand the genetic basis of natural selection. Teachers also had difficulty in applying the Darwinian model of evolution. Although the teachers could describe the process of natural selection, they could not apply it to other situations, such as industrial melanism in peppered moths and the adaptations of plants and animals in mangrove forest. One teacher did not allow students to attempt to explain these phenomena. She read the answers from the manual to the students and moved to the next topic. Another two teachers asked the students to provide explanations, but they ignored student misconceptions. Another teacher skipped this step completely. In discussing natural selection, these teachers usually referred to the examples from the IPST textbook that they were familiar with: finch, Galapagos tortoise and giraffe

In lesson plan five, Evolving Populations, the teachers had a number of difficulties in understanding the Hardy-Weinberg Principle. First and foremost, they could not explain the relevance of the principle to evolution. One teacher paid much attention on the Hardy-Weinberg equations ($p^2 + 2pq + q^2 = 1$, $p + q = 1$). She often used it to determine unknown allele and genotypic frequencies. However, she never explained how it was derived and when it could be used. The equation can be used only if a population is assumed to be large with random mating, no natural selection, no mutation, and no migration.

Secondly, some teachers did not know how to solve Hardy-Weinberg problems. At the end of Lesson Four, the students were asked to work in groups to solve Hardy-Weinberg problems. Two teachers did not explain the procedure and how the Hardy-Weinberg Principle was used in that context to detect evolutionary change. They simply wrote the procedures from the manual on the blackboard and asked the students to take notes. In addition, the teachers could not identify the assumptions of the principle in the "Counting Button" exercise, which is designed to demonstrate the Hardy-Weinberg Principle. In discussing the exercise, they could not explain to the students how the experiment simulated random mating, no selection, and no net mutation. All teachers paid no attention to these points even though they were made aware of them by the lesson plan and in the meetings.

Teacher Understanding of the ELU Activities

The teachers did not understand two activities, "Comparing Models of Evolution" and "Counting Buttons", and could not run them as well as was hoped. In Lesson Two, Models of Evolution, the students were first asked to: listen to and read the original writings of Paley, Lamarck and Darwin; find the key ideas of each model;

identify its assumptions; and make a comparison between the three models. In step 2, they were asked to use the three models to explain a particular evolutionary phenomenon, industrial melanism in peppered moths, and to decide which model provided the best explanation for the data. Then, in step 3, the students applied neo-Darwinism as the scientific model to explain the adaptation of plants and animals in mangrove forest.

However, the teachers did not follow these steps. After the tape was finished, three teachers asked their students to identify the differences between the three writings immediately. They did not allow the students to make sense of the new information well enough, nor to identify the key ideas and the assumptions that made the models different. The students would not be able to distinguish between the three models unless they understood each model thoroughly. The teachers were not aware that this teaching process can not be reduced, because it is central to enhancing student understanding of evolution by allowing students to assess their existing models and strengthen understanding of the scientific models.

In "Counting Buttons", a lab exercise about the Hardy-Weinberg Principle in Lesson Five, all teachers did not feel able to run the activity on their own. They asked the researcher to explain the procedure to the students and help them manage the class. The teachers said that they were confused about the procedure. It involved many steps, and the teachers were worried they would mix them up and would not be able to give assistance to the students when requested. In this lesson, the students were asked to solve Hardy-Weinberg problems about the human M-N blood group system, provided in their worksheet. The students calculated allele and genotypic frequencies and examined changes in the allele frequencies over time. One teacher did not solve the problem as the lesson plan suggested. This problem was intended to demonstrate how to examine the change in allele frequency over generations in the population at genetic equilibrium and when it undergoes natural selection. However, this teacher gave her attention to problem solving strategies. She gave students a tip to figure out allele and genotypic frequencies from a given population as fast as possible, using the Hardy-Weinberg equations.

The weekly discussions confirmed that teachers need to understand their subject matter deeply and thoroughly, so that they can help their students develop a scientific understanding of evolution, show them how the various concepts are related, and address student misconceptions about the topic.

Limitations to implementation of the ELU

Time constraints

The teachers felt that the schedule was too tight. They argued that the students needed more time than was allocated to think and work on the activities. In the second lesson ("Models of Evolution"), for example, the students were asked to listen to and read excerpts from original papers by Paley, Lamarck and Darwin, determine the assumptions of each model of evolution, and make a comparison of the three models. Many students could not do this on a single hearing of the tape. They asked the teacher to replay the tape recorder and give them more time to work on it.

The teachers also found that a number of students could not make sense of what they were trying to explain and some students did not have a scientific understanding of the fundamental concepts of evolution such as the nature and sources of genetic variation, or Mendel's first law of segregation. This meant that they had to spend time reviewing and clarifying the various concepts. Moreover, many teaching periods were lost during the implementation of the ELU: the boys went for military training for a week; the students went out to get university entrance application forms; all students took the National Test for two days; some teachers had to attend a school seminar. As a result, most of the teachers could not finish the last two lessons of the unit and run the activity "Evolution and Classification of

Caminalcules". The teachers provided extra periods for these lessons and gave a lecture to summarize the key ideas instead of running the activity.

Teacher beliefs

The implementation of the ELU was dramatically influenced by how much teachers valued this subject, and the proportion of evolution content in the university entrance examination. One teacher thought that evolution was not difficult; the students could read from the textbook and develop understanding by themselves. She argued that the effective teaching strategies for evolution were to recap key ideas and let the students do the former entrance exams as much as possible. To her, evolution was not as important as other topics of biology because comprised the smallest proportion of the entrance examination. "My job is to help them pass the entrance examination", she said. In previous years, she had allocated most of the time in the second semester to the Genetic Unit but spent less than five periods for evolution; which was less than the 12 periods suggested by the IPST textbook. She taught only the Hardy-Weinberg Principle and human evolution, the main evolution topics in the entrance examination. Consequently, she expressed strong disagreement with the omission of human evolution from the ELU. This teacher insisted on using and teaching and used her own material on this topic and Hardy-Weinberg Principle. The effect of teacher belief on the implementation of the ELU will be elaborated in case study Two; Pasak School.

Case Study One: Racha School

School Context

Racha School is located in a suburban area of Bangkok. It is a large school with 2725 students in sixty-three classes. Ninety-eight percent of students are Buddhist. The rest encompass Christian and Muslim. They mostly come from middle class families. In grade 12, in the 2004 academic year there were eight classes, two of which were following the Science and Mathematics program. The students in this program study Physics four periods a week, and Chemistry and Biology each occupy three periods a week. Each period lasts for fifty minutes. One semester consists of eighteen weeks including teaching and two examination sessions; mid-term and final.

Teacher and Student Background

Both classes were taught by Kanika, a teacher with 10 years' experience in teaching evolution. She was 52 years old and had a Bachelor of Education in science teaching. Despite this, she had no specific training in teaching evolution and had not taken any courses on evolution in university. Instead, Kanika had studied evolution on her own from the Grade 12 Biology textbook when she started teaching evolution. She admitted that she was not confident in many evolutionary topics, such as theories of evolution, mechanisms of evolution and the Hardy-Weinberg principle. She said that she had a problem about the content of evolution and she needed to overcome this difficulty. She had not been clear about the Hardy-Weinberg principle since she started teaching this topic ten years ago. She knew how to solve Hardy-Weinberg problems and could explain the procedures to students but she wondered about the relevance of the Hardy-Weinberg principle and how it helped her understand evolution. In 2004 the Evolution Learning Unit was implemented in both grade 12 Biology classes; one class of high achievers and the other of average achievers. There were 35 students in each class.

Classroom Setting

Karnika usually taught in a biology laboratory that contained sufficient science equipment for all groups of students to experience hands-on work. The school employed a laboratory assistant to prepare scientific apparatus for teachers and take care of the scientific apparatus, which was all in good condition, and the laboratories. However, the laboratories were sometimes used by other teachers. When this happened, Karnika had to teach in a classroom which was not well set up for learning science: it was not fully equipped and was crowded with rows of tables. The classroom was also old and untidy.

Research Question III: How did the teachers implement the ELU in their own classrooms?

The section focuses on the implementation of the ELU in Racha School by Karnika. Teaching practice including teaching strategies, the use of instructional media and assessment methods is described. Classroom interaction between the teacher and students was also examined by taking multiple sources of data into consideration: student response from a questionnaire, classroom observation and in-depth interviews. In the end of this section, teacher's conceptual difficulty and her awareness of students' non-scientific ideas and the effect on the implementation of the ELU on the teacher's future teaching practice are discussed.

Teaching practice

Karnika followed the instructional guidelines of ELU and made use all instructional media and materials. During the implementation of the ELU, Karnika had changed her teaching strategy noticeably. She adhered to a constructivist teaching approach instead of simply transmitting knowledge of evolution. She facilitated student construction of new ideas or concepts based upon their current knowledge. She probed students' prior ideas before introducing a new concept. She gave students opportunities for hands-on work and encouraged them to discuss their results in order to come up with the conclusions by themselves. As for assessment, Karnika used a variety of ways to assess their learning; test scores, class presentations, worksheets, assignments, and their participation in classroom work, as suggested by the ELU. The assessments are conducted throughout the instructional process to monitor students' progress and provide feedback on their strengths and weaknesses. The students noticed this change in her teaching practice and thought that this would give them an opportunity to learn science efficiently.

> “I think she has changed a lot since she started this unit. She came to our class with more questions than ever. She did not give the correct answer right off. Instead, she said we would know the answer after doing the activities. My friends and I love her activities very much. We feel more involved in the activities. It was so nice to be able to handle things and work with friends”
>
> Vanvisa, a female student from class 6/2

The data from classroom observations is consistent with this student’s opinion. In the topic Evidence for Descent with Modification, Karnika first asked the students to observe and compare the forelimbs of whale, cat, bat and human in terms of the number and the position of humerus, radius, ulna and carpal. She then encouraged students to figure out the reason why these various animals, living in different habitats and using their forelimbs for totally different purposes, had such similar internal structure. After having a discussion, the students come up with the conclusion that the forelimbs of these animals must have been derived from the same structures in a common ancestor. The concept name, “homologous structure” was given to students at the end of the lesson. Karnika employed the same strategy for other evidence of descent from a common ancestry. In previous academic years, she said she had spent less than ten minutes on this topic. At that time, she and her students had gone through the textbook together. The students did not have much chance to think and talk about this topic.

<u>Classroom interaction</u>

When classroom interaction was investigated, it found that Karnika entered into a dialogue with the students, trying to help the students to refine their understanding until it corresponded with the scientific understanding of a given topic. Below is a discursive interaction between Karnika and her students on the adaptive significance of frogs’ skin color.

Karnika:	… Which color of frogs do you think the egret would prefer in this case?
Ss:	Yellow
Karnika:	Yeah. The egret would eat the yellow frogs first. What theory of evolution do you think this phenomenon corresponds with? Lamarck or Darwin?
Ss:	Darwin….Lamarck (speak quietly)
Karnika:	You may not be clear about it. OK let's try this. If we take a look at the number of each color, which color do you think will become less and less when the time goes by?
All:	Yellow
Karnika:	Why?
S2:	The egret will eat the yellow so they can not reproduce and pass on the yellow skin trait to the next generation. Gradually, the yellow will disappear from the population.
Karnika:	Excellent! Can you tell me, what theory of evolution does what your friend has just explained to me correspond to?
All:	Darwinism
Karnika:	Yes. O.K. think in another way, suppose you are Lamarck, how would you explain the phenomenon?
S3:	The yellow frogs themselves gradually changed their skin color to blend in with the background. They will finally become green frogs.
Karnika:	Yes, you are right. Darwin will never explain the change in that way. The proportion of each variation instead do as those having a trait favorable to the environment will better survive and reproduce. They have a greater chance to pass on their trait to offspring.

From the dialogue, Karnika first asked the students to carefully observe the picture of an egret and frogs and asked them a series of questions from simple factual to reasoning questions. When the students could answer a question, Karnika subsequently asked more complex questions to help students make meaning of what they had just said and so to construct a model of natural selection. She developed many thoughtful questions besides those recommended in the lesson plan; for example, asking students to explain the phenomenon from a Lamarckian perspective. She continually took student responses into account. When she noticed that most of the students could not identify a model of evolution from the given example, she put the question in another way, so some students could answer the question and share their answer with the rest of the class.

Teacher's conceptual difficulty and her awareness on students' non-scientific idea

Teacher's conceptual difficulties were identified during in this discussion. During a classroom dialogue on the adaptive significance of frogs' skin color, Karnika did not discuss the origin of variation with in a give population. She did not ask the students how the skin colors, yellow and green, first occurred in a population. She had already taught this concept in Genetics Unit. She did not refer to it in the discussion of natural selection. Karnika might have forgotten to do so or have not seen the connection of these concepts. This concept is an essential concept component of evolutionary process. Without scientific understanding, the student could not explain source of genetic variability in a population, the raw material that natural selection acts upon.

The effect of the implementation of the ELU on teacher's future teaching

In later weeks of the implementation, it was obvious that Karnika felt more comfortable with teaching the ELU. She adapted the intervention to suit her own style and classroom requirements. In discussing natural selection, using the earlier example of frogs and egrets, she developed many thoughtful questions besides those recommended in the lesson plan; for example, asking students to explain the phenomenon from a Lamarckian perspective. This helped students distinguish between Darwinian and Lamarckian explanations for the situation. She said that she had got a lot of ideas to teach evolution. She herself also had developed understanding of evolution throughout the process of implementation. She felt more confident in teaching evolution and would be continually using and adapting some activities of ELU for the following academic years.

In conclusion, Karnika taught evolution following the approach of the ELU. She employed a constructivist teaching approach, used a variety of techniques to assess student learning, and made use the instructional material of the intervention. The teacher placed more emphasis on social constructivism, whereby knowledge is socially constructed and mediated by social interactions in teaching evolution. Karnika had difficulties in understanding Hardy-Weinberg Principle and the genetic basis of natural selection. Therefore, she could not explain and run some activities. However, Karnika adjusted progressively to the intervention and became more confident in teaching the material. She found the intervention worked for her students because they paid more attention to the lessons. She herself developed content knowledge and got many teaching strategies from the implementation.

Research Question IV: Does the Evolution Learning Unit (ELU) enhance student understanding of Evolution?

An Evolution Diagnostic Test (EDT) (see appendix A) was administered to the grade 12 Biology students at Racha Pitthayalai school, before and after the implementation of the ELU, to study the effect of the intervention on student understanding of evolution. In the test, the students first read information about a particular situation, also called a context of evolution, and then chose from a list the statement that they felt best explained a concept of evolution. Each statement in the list represented a particular model of evolution; Neo-Darwinism, Lamarckism, Creation (young earth), Progressive Creationism. There were five contexts in the test, relating to five organisms: bentgrass, moth, guppy, *E. coli*, and finch. The structure and the development of EDT were discussed in details in Chapter Three: Methodology. This section aims not only to investigate the effect of the intervention on student learning but also to study the use of models by students, the strength of the students' prior models, and how resistant they are to change. Here the study makes a valuable contribution towards our knowledge of student models in science. These are much more complex than we had expected.

To study the effect of the ELU on student understanding of evolution, percentages of students using a particular model of evolution between pretest and posttest were compared. This determines whether there was a change in the proportion of students using the scientific model after the implementation of ELU. The findings from this examination were elaborated with the analysis of use of models of evolution of individual students between pretest and posttest. This analysis looked at the number of students who changed and did not change to the scientific model after the instruction and classified the use of models into four categories: Sci to Sci (use the scientific model over pretest and posttest); Sci to Non-Sci (use a non-scientific model in pretest but the scientific model in posttest); Non-Sci to Non-Sci (use a non-scientific model in both pretest and posttest); and Non-Sci to Sci (use a non-scientific model in pretest but the scientific model in posttest).

Finding I: ELU enhances student understanding of evolutionary process in the concepts of role of variation, change in a trait, and role of environment. The students did not use the scientific model to explain origin of variation and speciation.

Origin of variation

The most common model for origin of variation in all contexts in both pretest and posttest is not Neo-Darwinism except in *E.coli* posttest (Table 6.3). In the contexts of bentgrass and moth, around 50 percent or more preferred Progressive Creationism in pretest and posttest. In guppy, there is a shift of the most common model from Lamarckism in pretest by 43.60 percent to Progressive Creationism by

45.90 percent. In *E. coli*, even though there is a shift of the most common model from Progressive Creationism, to Neo-Darwinism in posttest, the percentages of the two models are pretty close, 41 percent for Progressive Creationism and 44.30 percent for Neo-Darwinism. In Finch, the most common model in pretest and posttest is Lamarckism by 54.50 and 49.20 percent respectively.

Table 6.3 The Most Common Model for Each Context of Origin of Variation (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	PROG	PROG	LAM	PROG	LAM
	60.00	50.90	43.60	47.30	54.50
Post-test	PROG	PROG	PROG	NEO	LAM
	49.20	52.25	45.90	44.30	49.20

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

The use of non-scientific models over pretest and posttest is confirmed when one examines the use of models between pretest and posttest of individual students (table 6.4). It was found that in all contexts, the majority of students preferred to use non-scientific models over pretest and posttest; 68 percent in bentgrass, 68.75 percent in moth, 69.39 percent in guppy, 40.90 percent in *E. coli* and 53.07 percent in finch. These percentages comprised the use of the same non-scientific model the most. For example, 68 percent of Non-Sci to Non-Sci category in bentgrass is contributed by 38 percent of students using Progressive Creationism. The percentages of other categories are much less than that of Non-Sci to Non-Sci, Sci to Sci category, for example, its percentage in all contexts except *E. coli* is less than 5 percent.

Classroom observation and in-depth interviews were carried out to investigate the root of this conceptual difficulty. Discussing origins of variation, many students said they were aware of the appearance of variation in a population and could explain how a particular environment worked on such variation within a population. This group of students said they always got stuck when asked to explain how the variation first occurred in a population. To them, it seemed to be most possible that the new trait was derived from the original trait by accident. Some of these students could not explain the term "accident". They called it an unknown sudden process. The other students thought it was mutation. Other students said they knew the sources of variation: gene recombination and mutation. They said they had learned this from a previous unit, Genetics, but they had not known before that this concept related to the process of natural selection. The students were not made aware of this by their teacher. This confirms an earlier observation, discussed in the third research question that Karnika did not review this concept, nor link it to the process of natural selection, even though it was strongly advised in the lesson plan and in the meeting.

Table 6.4 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain The Concept of Origin of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(2)	(4)	(2)	(4.17)	(2)	(4.08)	(6)	(12.20)	(2)	(4.08)
(1→ 1)	2	4	2	4.17	2	4.08	6	12.20	2	4.08
Scientific to Non –Scientific	(8)	(16)	(6)	(12.50)	(6)	(12.24)	(6)	(12.20)	(6)	(12.24)
(1→ 2)	4	8	3	6.25	4	8.16	5	10.20	3	6.12
(1→ 3)	3	6	3	6.25	2	4.08	0	0.00	3	6.12
(1→ 4)	1	2	0	0.00	0	0.00	1	2.04	0	0.00
Non - Scientific to Non – Scientific	(34)	(68)	(33)	(68.75)	(34)	(69.39)	(20)	(40.90)	(26)	(53.07)
(2→ 2)	19	38	8	16.67	6	12.24	12	24.49	1	2.08
(2→ 3)	1	2	10	20.83	5	10.20	1	2.04	6	12.24
(2→ 4)	3	6	0	0.00	0	0.00	1	2.04	0	0.00
(3→ 2)	3	6	6	12.50	9	18.37	4	8.16	5	10.20
(3→ 3)	4	8	5	10.42	7	14.28	1	2.04	13	26.53
(3→ 4)	1	2	0	00.00	3	6.12	0	0.00	0	0.00
(4→ 2)	1	2	2	4.17	2	4.08	0	0.00	0	0.00
(4→ 3)	1	2	1	2.03	2	4.08	1	2.04	1	2.08
(4→ 4)	1	2	1	2.03	0	0.00	0	0.00	0	0.00
Non – Scientific to Scientific	(6)	(12)	(7)	(14.58)	(7)	(14.29)	(17)	(34.70)	(15)	(30.61)
(2→ 1)	6	12	3	6.25	3	6.12	11	22.45	6	12.24
(3→ 1)	0	0	4	8.33	2	4.08	6	12.24	9	18.37
(4→ 1)	0	0	0	0.00	2	4.08	0	0.00	0	0.00
TOTAL	50	100	48	100	49	100	49	100	49	100

1 = Neo-Darwinism 2 = Progressive Creationism 3 = Lamarckism 4 = Creationism (Young Earth)

Role of variation

The most common model for role of variation in posttest of all contexts is Neo-Darwinism (Table 6.5). In bentgrass, *E. coli* and finch, the majority of students used Neo-Darwinism in both pretest and posttest. There is an increase in percentage of the scientific model in these contexts. In *E.coli*, for example, the percentage of Neo-Darwinism increases from 52.70 percent in pretest to 83.60 percent in posttest. In moth and guppy, it was found that there was a shift from the most common model towards the scientific model; Lamarckism to Neo-Darwinism. The percentage of the scientific model in these two contexts increases by 20 percent.

Table 6.5 The Most Common Model for Each Context of Role of Variation (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	LAM	LAM	NEO	NEO
	43.60	36.40	29.10	52.70	69.10
Post-test	NEO	NEO	NEO	NEO	NEO
	45.90	55.70	47.50	83.60	82.00

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationsim (young earth)

The use of the scientific model was elaborated in the examination of the use of model between pretest and posttest of individual students (Table 6.6). It found that Sci to Sci is the most common category in *E. coli* and finch by 46.80 and 64.58 and Non-Sci to Non- Sci is the most common category in bentgrass, moth, and guppy by 42, 41.66 and 35.42 percent respectively. However, the percentage of Non-Sci to Sci category is noticeable in almost contexts; 22.92 percent in moth, 29.17 percent in guppy, 36.20 percent in E. coli and 20.83 percent in finch.

Table 6.6 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(16)	(32)	(11)	(22.92)	(7)	(14.58)	(22)	(46.80)	(31)	(64.58)
(1→ 1)	16	32	11	22.92	7	14.58	22	46.80	31	64.58
Scientific to Non –Scientific	(6)	(12)	(6)	(12.50)	(10)	(20.83)	(4)	(8.51)	(3)	(6.25)
(1→ 2)	1	2	2	4.17	2	4.17	2	4.25	1	2.08
(1→ 3)	3	6	3	6.25	2	4.17	0	0.00	0	0.00
(1→ 4)	2	4	1	2.08	6	12.5	2	4.25	2	4.17
Non - Scientific to Non - Scientific	(21)	(42)	(20)	(41.66)	(17)	(35.42)	(4)	(8.51)	(4)	(8.33)
(2→ 2)	1	2	4	8.33	3	6.25	1	2.13	4	8.33
(2→ 3)	3	6	4	8.33	2	4.17	1	2.13	0	0.00
(2→ 4)	1	2	2	4.17	1	2.08	1	2.13	0	0.00
(3→ 2)	1	2	3	6.25	1	2.08	1	2.13	0	0.00
(3→ 3)	5	10	4	8.33	2	4.17	0	0.00	0	0.00
(3→ 4)	3	6	0	0.00	1	2.08	0	0.00	0	0.00
(4→ 2)	2	4	2	4.17	2	4.17	0	0.00	0	0.00
(4→ 3)	3	6	1	2.08	3	6.25	0	0.00	0	0.00
(4→ 4)	2	4	0	0.00	2	4.17	0	0.00	0	0.00
Non – Scientific to Scientific	(7)	(14)	(11)	(22.92)	(14)	(29.17)	(17)	(36.20)	(10)	(20.83)
(2→ 1)	2	4	7	14.58	5	10.42	5	10.64	3	6.25
(3→ 1)	5	10	4	8.33	4	8.33	6	12.76	4	8.33
(4→ 1)	0	0	0	00.00	5	10.42	6	12.76	3	6.25
TOTAL	50	100	48	100	48	100	47	100	48	100

1 = Neo-Darwinism 2 = Lamarckism 3 = Creationism (Young Earth) 4 = No Effect…Same Species

Change in a trait

The majority of students did not use a particular model to explain change in a trait in any contexts in both pretest and posttest (Table 6.7). In bentgrass, the most common model in pretest and posttest is Neo-Darwinism by 36.40 and 44.30 percent respectively. In moth and guppy, Progressive Creationism is the most common model by 63.60 and 51.10 percent in pretest and posttest of moth and by 30.90 and 31.10 percent in pretest and posttest of guppy. In *E. coli* and finch, there is a shift to the most common model from non-scientific model; Lamarckism in *E. coli* and Progressive Creationism in finch, to the scientific model. In *E. coli* and finch, the percentage of Neo-Darwinism over pretest and posttest rises from 23.60 to 54.10 percent and from 40 to 62.30 percent respectively.

Table 6.7 The Most Common Model for Each Context of Change in a Trait (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	PROG	PROG	LAM	PROG
	36.40	63.60	30.90	50.90	45.50
Post-test	NEO	PROG	PROG	NEO	NEO
	44.30	51.10	31.10	54.10	62.30

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

This inconsistence use of models is consistent with the examination of the use of models between pretest and posttest of individual students (Table 6.8). Three categories were found the most prevalent among the five contexts; Non-Sci to Non-Sci in bentgrass (37.50 percent) and guppy (52.38 percent), Sci to Non-Sci in moth (36 percent), and Non-Sci to Sci in *E. coli* (41.67 percent) and Sci to Sci and Non-Sci to Sci by the same percentage in Finch (30.61). In bentgrass and moth, the percentage of Non-Sci to Sci category is close to that of the most predominant models by 25.00 percent in bentgrass and 28 percent in moth. The results indicate that the students lacked confidence in any model so they used many models interchangeably across different contexts. This can be explained when looking back at their classroom experience.. In the discussion of the adaptation of frog skin color and the industrial melanism in peppered moth, Karnika did not emphasize that natural selection occurred at the level of a population; the proportion of individuals with the character changed, not the character itself.

Table 6.8 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Change in a Trait

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(8)	16.67	(3)	(6.00)	(3)	(7.14)	(8)	(16.67)	(15)	(30.61)
(1→ 1)	8	16.67	3	6.00	3	7.14	8	16.67	15	30.61
Scientific to Non –Scientific	(10)	20.83	(18)	(36.00)	(9)	(21.43)	(2)	(4.17)	(5)	(10.20)
(1→ 2)	0	0.00	0	0.00	2	4.76	0	0.00	2	4.08
(1→ 3)	7	14.58	16	32.00	3	7.14	0	0.00	2	4.08
(1→ 4)	3	6.25	2	4.00	4	9.52	2	4.17	1	2.04
Non - Scientific to Non - Scientific	(18)	37.50	(15)	(30.00)	(22)	(52.38)	(18)	(37.50)	(14)	(28.58)
(2→ 2)	1	2.08	0	0.00	2	4.76	0	0.00	0	0.00
(2→ 3)	0	0.00	2	4.00	3	7.14	0	0.00	1	2.04
(2→ 4)	1	2.08	0	0.00	0	0.00	0	0.00	1	2.04
(3→ 2)	0	0.00	2	4.00	3	7.14	0	0.00	3	6.12
(3→ 3)	2	4.17	7	14.00	6	14.28	1	2.08	4	8.16
(3→ 4)	7	14.58	0	0.00	1	2.38	4	8.33	1	2.04
(4→ 2)	0	0.00	0	0.00	2	4.76	1	2.08	0	0.00
(4→ 3)	3	6.25	3	6.00	1	2.38	4	8.33	4	8.16
(4→ 4)	4	8.33	1	2.00	4	9.52	8	16.67	0	0.00
Non – Scientific to Scientific	(12)	25.00	(14)	(28.00)	(8)	(19.05)	(20)	(41.67)	(15)	(30.61)
(2→ 1)	0	0.00	1	2.00	2	4.76	0	0.00	0	0.00
(3→ 1)	3	6.25	11	22.00	3	7.14	8	16.67	15	30.61
(4→ 1)	9	18.75	2	4.00	3	7.14	12	25.00	0	0.00
TOTAL	48	100	50	100	42	100	48	100	49	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Progressive Creationism 4 = Lamarckism

Role of environment

Neo-Darwinism is the most common model for the role of environment in posttest of all contexts (Table 6.9). In bentgrass, guppy and finch, it is the most common model in both pretest and posttest. In finch, in a particular, the percentage of students using Neo-Darwinism significantly increases from 52.10 percent in pretest to 70.50 percent in posttest. The shift of the most common model between pretest and posttest is found in moth and *E. coli*: 47.30 percent of Lamarckism in pretest to 67.20 percent of Neo-Darwinism in posttest in moth and 41.80 percent of Lamarckism in pretest to 41 percent of Neo-Darwinism in posttest in *E. coli*. The percentage of students using the scientific model between pretest and posttest increases sharply from 9.1 to 41 percent in *E. coli* and 32.70 to 67.20 percent in moth.

Table 6.9 The Most Common Model for Each Context of Role of Environment

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	LAM	NEO	LAM	NEO
	47.30	47.30	49.10	41.80	52.10
Post-test	NEO	NEO	NEO	NEO	NEO
	45.90	67.20	36.10	41.00	70.50

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

The use of the scientific model above coincides with the results of the examination of the use of models between pretest and posttest of individual students (Table 6.10). The combination of the percentages of Sci to Sci and Non-Sci to Sci categories is the most predominant in all contexts especially *E. coli* and finch. Finch, for example, the percentages of Sci to Sci and Non-Sci to Sci are 51.16 and 25.58 percent respectively.

Table 6.10 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Environment

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(13)	(26.53)	(8)	(16.33)	(9)	(18.75)	(3)	(5.66)	(22)	(51.16)
(1→ 1)	13	26.53	8	16.33	9	18.75	3	5.66	22	51.16
Scientific to Non –Scientific	(11)	(22.45)	(6)	(12.24)	(15)	(31.25)	(2)	(3.78)	(6)	(13.95)
(1→ 2)	3	6.12	1	2.04	1	2.08	1	1.89	0	0.00
(1→ 3)	3	6.12	2	4.08	5	10.42	1	1.89	4	9.30
(1→ 4)	5	10.20	3	6.12	9	18.75	0	0.00	2	4.65
Non - Scientific to Non - Scientific	(16)	(32.65)	(23)	(46.94)	(16)	(33.33)	(28)	(52.83)	(4)	(9.31)
(2→ 2)	0	0.00	0	0.00	2	4.17	2	3.77	0	0.00
(2→ 3)	2	4.08	1	2.04	0	0.00	5	9.43	0	0.00
(2→ 4)	2	4.08	1	2.04	2	4.17	3	5.66	1	2.32
(3→ 2)	0	0.00	6	12.24	0	0.00	2	3.77	0	0.00
(3→ 3)	2	4.08	10	20.41	1	2.08	8	15.09	0	0.00
(3→ 4)	3	6.12	4	8.16	3	6.25	4	7.55	1	2.32
(4→ 2)	2	4.08	1	2.04	2	4.17	2	3.77	0	0.00
(4→ 3)	0	0.00	0	0.00	3	6.25	0	0.00	1	2.32
(4→ 4)	5	10.20	0	0.00	3	6.25	2	3.77	1	2.32
Non – Scientific to Scientific	(9)	(18.37)	(12)	(24.49)	(8)	(16.67)	(20)	(37.73)	(11)	(25.58)
(2→ 1)	4	8.16	1	2.04	1	2.08	9	16.98	2	4.65
(3→ 1)	2	4.08	10	20.41	3	6.25	8	15.09	6	13.95
(4→ 1)	3	6.12	1	2.04	4	8.33	3	5.66	3	6.98
TOTAL	49	100	49	100	48	100	53	100	43	100

1 = Neo-Darwinism 2 = Dominant/Recessive Genes 3 = Lamarckism 4 = Creationism (Young Earth)

Speciation

The majority of students preferred non-scientific models in explaining speciation in all contexts in pretest and posttest except moth (Table 6.11). In bentgrass, the most common models in pretest are Neo-Darwinism and Lamarckism by the same percentage (27.30 percent) while that of posttest is Lamarckism by 39.30 percent. In finch, the majority of students preferred Lamarckism in both pretest and posttest by 61.80 and 59 percent respectively. In *E. coli*, Lamarckism, the most common model in pretest by 45.50 percent is replaced by Mutation, the other non-scientific model by 42.60 percent in posttest. The shift of models from a non-scientific model to the scientific is found in guppy: Mutation (36.40 percent) to Neo-Darwinism (37.70 percent). Moth is the only context that Neo-Darwinism is the most common model in both pretest and posttest by 36.40 and 36.10 percent respectively.

Table 6.11 The Most Common Model for Each Context of Speciation (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E. coli*	Finch
Pre-test	NEO, LAM	NEO	MU	LAM	LAM
	27.30	36.40	36.40	45.50	61.80
Post-test	LAM	NEO	NEO	MU	LAM
	39.30	36.10	37.70	42.60	59.00

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth) MU = Mutation

The interchangeable use of models to explain the concept of speciation is consistent with the results of the examination of use of models between pretest and posttest of individual students (Table 6.12). The most predominant category of all contexts is Non-Sci to Non-Sci: 64.28 percent in bentgrass; 50 percent in moth, 57.14 percent in guppy, 68.75 percent in *E. coli* and 75.52 percent in finch. This high percentage of Non-Sci to Non-Sci category is contributed by the percentage of students applying the same non-scientific models in both pretest and posttest the most.

For instance, 75.52 percent of Non-Sci to Non-Sci in finch encompasses 38.77 percent of students using Lamarckism over pretest and posttest.

In teaching speciation, this teacher covered the ELU topics “speciation” and “Macro evolution” in the available time, and also spent an extra two periods to summarize the two lessons, giving a lecture highlighting the key points of each lesson. In doing this, she did not follow the ELU teacher manual. The students said they did not do any activities and exercise in the class. There was no discussion on the concept at that stage. This might be the cause of the difficulty in understanding the two concepts.

Table 6.12 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Speciation

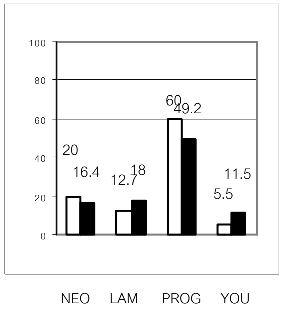
Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(5)	(8.94)	(9)	(16.07)	(5)	(10.20)	(2)	(4.17)	(1)	(2.04)
(1→ 1)	5	8.93	9	16.07	5	10.20	2	4.17	1	2.04
Scientific to Non –Scientific	(8)	(14.28)	(6)	(10.71)	(1)	2.04	(7)	(14.58)	(5)	(10.20)
(1→ 2)	2	3.57	2	3.57	0	0.00	1	2.08	2	4.08
(1→ 3)	5	8.93	1	1.78	0	0.00	2	4.17	3	6.12
(1→ 4)	1	1.78	3	5.36	1	2.04	4	8.33	0	0.00
Non - Scientific to Non - Scientific	(36)	(64.28)	(28)	(50)	(28)	(57.14)	(33)	(68.75)	(37)	(75.52)
(2→ 2)	7	12.50	4	7.14	2	4.08	0	0.00	1	2.04
(2→ 3)	4	7.14	1	1.78	1	2.04	1	2.08	6	12.24
(2→ 4)	2	3.57	7	12.50	2	4.08	3	6.25	1	2.04
(3→ 2)	3	5.36	5	8.94	4	8.16	2	4.17	4	8.16
(3→ 3)	9	16.07	1	1.78	3	6.12	7	14.58	19	38.77
(3→ 4)	1	1.78	3	5.36	3	6.12	10	20.83	1	2.04
(4→ 2)	3	5.36	4	7.14	2	4.08	2	4.17	1	2.04
(4→ 3)	3	5.36	1	1.78	4	8.16	2	4.17	3	6.12
(4→ 4)	4	7.14	2	3.57	7	14.28	6	12.50	1	2.04
Non – Scientific to Scientific	(7)	(12.50)	(13)	(23.22)	(15)	(30.61)	(6)	(12.5)	(6)	(12.24)
(2→ 1)	4	7.14	5	8.94	6	12.24	0	0.00	0	0.00
(3→ 1)	2	3.57	5	8.94	4	8.16	3	6.25	5	10.20
(4→ 1)	1	1.78	3	5.36	5	10.20	3	6.25	1	2.04
TOTAL	56	100	56	100	49	100	48	100	49	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Lamarckism 4 = Mutation

Finding II: To explain the evolutionary process, Thai students did not hold a single model in their mind. They instead hold many and applied the one that seems most reasonable to them, for a particular context and concept and this is consistent in both pre-test and post-test.

An examination of the percentage of students using a particular model to explain a concept of evolution shows that the percentage using that model varied considerably across the five contexts of questions (see Table 6.13 by columns). For contexts relating to the concept of change in a trait, for example, no one model was chosen across all five contexts; this was the case in both pre- and post-tests. The percentage of a particular model for this concept is varied across different contexts. The percentages of students using Progressive Creationism in pretest are 3.6 percent in bentgrass, 63.60 percent in moth, 30.09 percent in guppy, 23.60 percent in *E. coli* and 45.50 percent in finch. The most common models across the concepts are also not the same. The test results also show that the students did not use one model to explain different underlying concepts of evolution (see figure 6.13 by rows). The percentage of a particular model across different evolutionary concept is wide ranging in both pretest and posttest. For instance, in the context of finch, the percentages of students using Neo-Darwinism in posttest are 31.10 percent in origin of variation, 82 percent in role of variation, 62.30 percent in change in a trait, 70.50 percent in role of environment, and 14.80 percent in speciation.

Table 6.13 The Percentages of Karnika's Students Using a Particular Model between Pretest and Posttest to Explain Various Concepts of Evolution across Five Contexts of Questions

<table>
<tr><th>Concepts / Contexts</th><th>origin of variation</th><th>role of variation</th><th>change in a trait</th><th>role of environment</th><th>speciation</th></tr>
<tr><td>Bentgrass</td>
<td>
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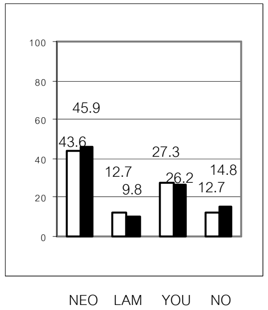
<td>
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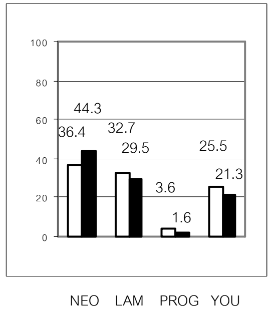
<td>
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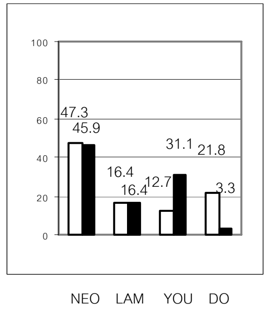
<td>
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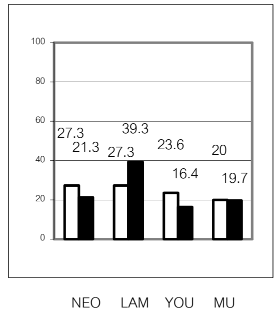
<td>
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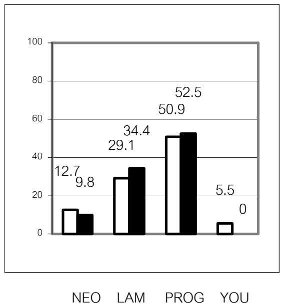
<tr><td>Moth</td>
<td>
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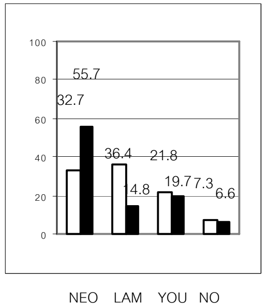
<td>
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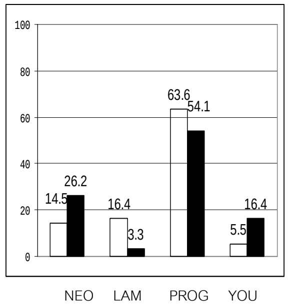
<td>
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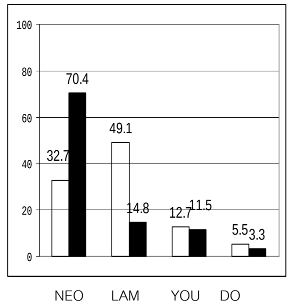
<td>
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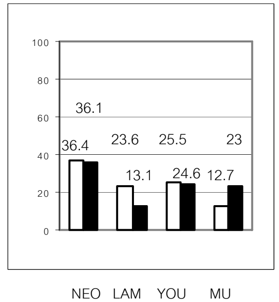
<td>
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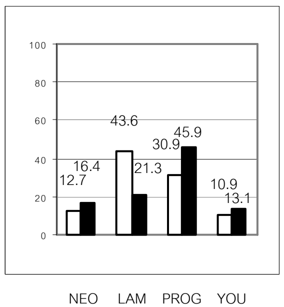
<td>
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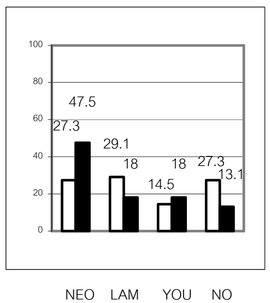
<td>
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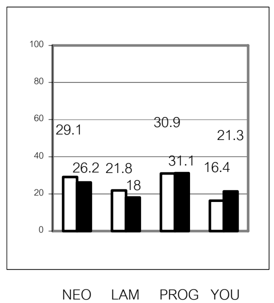
<td>
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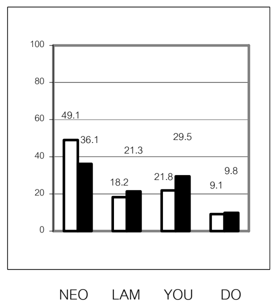
<td>
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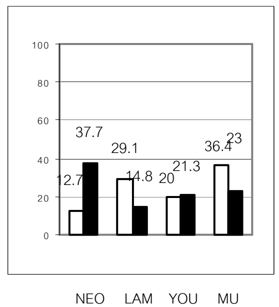
<td>
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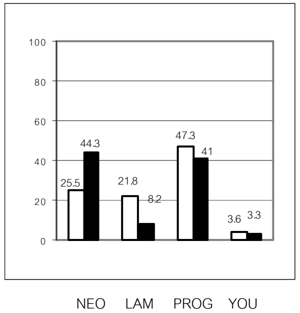
Table 6.13 (Cont'd)

<table>
<tr><th>Concepts / Contexts</th><th>origin of variation</th><th>role of variation</th><th>change in a trait</th><th>role of environment</th><th>speciation</th></tr>
<tr><td>E. coli</td>
<td>
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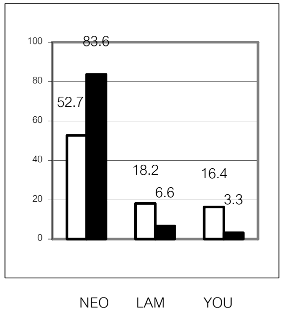
<td>
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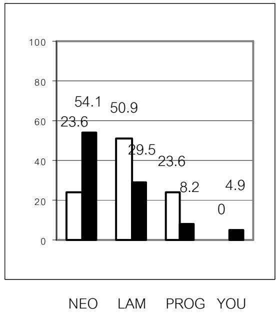
<td>
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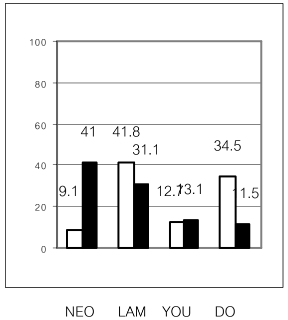
<td>
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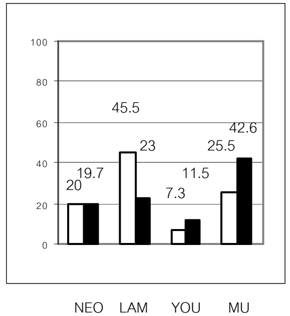
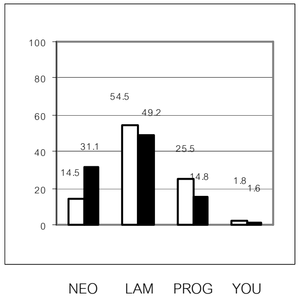
<td>
</td></tr>
<tr><td>Finch</td>
<td>
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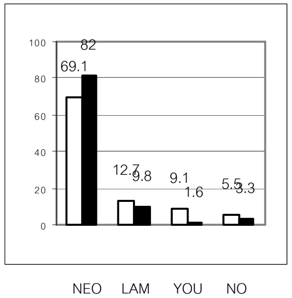
<td>
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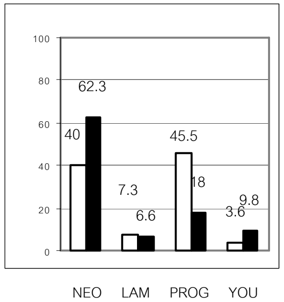
<td>
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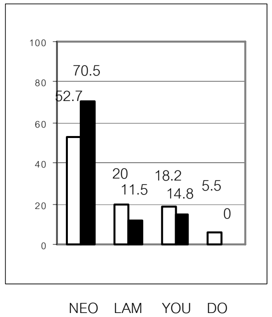
<td>
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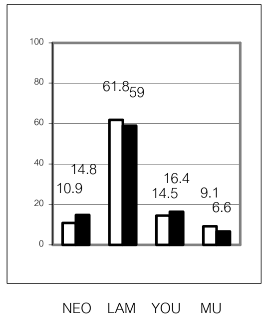
<td>
</td></tr>
<tr><td colspan="6">□ = Pretest ∎ = Posttest
NEO = Neo-Darwinism LAM = Lamarckism PROG = Progressive Creationism YOU = Creationism (Young Earth) MU = Mutation
NO = Variation has no effect</td></tr>
</table>

In-depth interviews with students and classroom observations were carried out in an attempt to determine why the students preferred to use a particular model in a particular context. The tests had showed that Lamarkism was commonly used among students to explain how traits change in the contexts of bentgrass and *E. coli*. Five students who employed a Lamarckian explanation in both contexts in pretest were interviewed. One student explained that he tended to use Lamarckism to explain the evolution of antibiotic resistance in *E. coli* and copper tolerance in bentgrass because the two characters were very similar, in the sense that the organisms involved adaptation of something inside the body of the organisms. Therefore, the two organisms should be explained in the same way and it was logical to him to explain these physiological traits by Lamarckism: accumulating the resistant and tolerant capacity bit by bit in their lifetime and passing the altered trait to their offspring. The same student also used Progressive Creationism in the other three contexts. When asked the reason, he said he found it was impossible to explain the change of visible traits of moth, guppy and finch by Lamarckism. This student preferred to use Lamarckism to explain the change of microscopic and physiological traits and Progressive Creationism to explain the change of macroscopic and morphological traits. As for the other four students, two of them did not give the reason why they preferred Lamarckism in *E.coli* and bentgrass. They said that Lamarckism sounded the most reasonable for the two contexts. The other two students did not give the answer.

> I could not explain these guys in that way. It sounds impossible that moth will change in its wing color bit by bit in their lifetime, from very white, slight gray, dark gray to black. I have never seen that. I think black peppered probably evolve from the original white suddenly when particular conditions are required. Maybe by a mutation (Sutat, a student from Racha Pitthayalai School)

Interestingly, one student said that she used Neo-Darwinism in the finch context, and Lamarckism and Progressive Creationism in other contexts, because she could recall that the finch was the example of natural selection in the IPST textbook and the teacher always went back to finches every time she referred to natural selection. So, she could recognize it in the test.

In conclusion, the students hold many models of evolution in their minds, and which one they choose to apply in a given context is very much influenced by contexts and concepts they encounter. The intervention enhanced student understanding of the role of variation, change in a trait, and role of environment. The students still have difficulty in understanding the concept of origin of variation and speciation which may be the consequence of their classroom instruction that did not put an emphasis on the two concepts. Teacher belief and her content knowledge have a great influence on the way the intervention implemented and student learning.

From the test results and classroom observation, it found that teacher's teaching practice had influence on the student learning of evolution. The difficulty in understanding the concepts of origin of variation and speciation might have been the consequence of the instruction that did not put an emphasis on these two concepts. From the interviews, some students said that they understood the origin of variation because they had studied it in a previous chapter. However, they could not see how this concept was related to the process of natural selection because their teacher had never referred to origin of variation in the discussion of natural selection. Consequently, they could not establish the connection between origin of variation and natural selection in the test. As for speciation, the teacher did not follow ELU in the last two lessons because of time constraint. She spent about one period to recap the key ideas in these two lessons. The students did not have an opportunity to engage the hands on activities that had been designed to help them gain insight into the process of speciation. According to the ELU, the lesson of speciation starts with asking student to identify the mechanisms of reproductive isolation from given situations. This exercise helps students explain why two different species can not interbreed when get into contact with each other even the two species look very similar or what make two species which once used to be the same species but later was separated genetically could not interbreed with each other. Then the ELU asked the students to study two cases of the speciation of Galapagos finches and bread wheat. The cases discuss the mechanism of allopatric and sympatric speciation followed by a number of questions about the text. These questions helped the students to become clear about the mechanism of speciation and also ask them to apply their knowledge to explain the speciation of other organisms. If the students had been involved in these activities, they might have developed a scientific understanding of speciation.

Case Study Two: Pasak School

School Context

Pasak School is located in Nontaburi, a province located directly north of Bangkok. It is a large co-educational school with 2992 students. During the study there were 12 classes at each grade of lower secondary level, with 50-55 students per class; and ten classes at each grade of upper secondary level, with 40-45 students per class. The majority of students come from middle class families. Ninety-eight percent of students are Buddhist. At the upper secondary level, the students are offered a variety of optional study programs in which they could choose to specialize in based on their aptitudes and interests: Science and Mathematics, Mathematics and English, English and French, and Vocational Studies. One semester lasts for 18 weeks, comprising 16 weeks for teaching and two weeks for mid-term and final examinations. An instructional period lasts for an hour, ten minutes longer than at Racha and Nanfah schools, because the school had already adjusted the time to fit the new timeframe required for the National Basic Curriculum B.E. 2544 (Ministry of Education, 2001). Pasak volunteered to be a pilot school and so it implemented the school-based curriculum one year ahead of other schools in this study.

Teacher and Student Background

Sarapee was the biology teacher who implemented the ELU in Pasak School. She was 57 years old and had been teaching biology and general science for 37 years, with a Bachelor of Education in Biology. She started her teaching career in a small school in Bangkok in 1967, but had worked at Pasak since 1977. Sarapee had attended a number of professional development workshops on various fields of biology such as botany, genetics, and biotechnology and the cutting edge of science such as nanotechnology and genetic engineering. Sarapee was trained by IPST on the design and development of a school-based curriculum and then she was asked by IPST to train other teachers in her school and those from other schools nearby to develop their school science program. In 2003, Sarapee was invited by Ministry of

Education to be the National Test development committee and by the Office of the Non-Formal Education Commission to develop a national test for science for the students in the non-formal education system. In academic year 2004, Sarapee taught Grade 12 Biology for four classes and Grade 7 Science for one class. Besides teaching, she was the supervisor of the science club and one of the discipline team.

Sarapee implemented the ELU in only one class, of high achieving students. There were 48 students in this class: 15 male and 33 female. Ninety-four percent of students were 17 to 18 years old. Forty-one percent of students had a GPA over 3.50, in a four-point grading system. Sixty-eight percent of them had a GPA for science higher than 3.00. By 51 and 49 percent, the students had decided to take or not to take biology in the entrance examination respectively. Taking biology test is a requirement for the students who want to pursue their study in the areas of Health Science, Medicine, Nursing, Agriculture, Science and other biology related areas. From the interview before the implementation, Sarapee's instruction was driven by the textbook and the assessment regime, with preparing her students for the university entrance examination as a key focus of her teaching. She raised her concerns about entrance examination.

> …I accept that I have pushed them too much. Grade 12 teachers were all under pressure. We were expected from the principal, the parents and even our students to help them have seats in the university. Sarapee, a Grade12 biology teacher, Pasak Vittayakhom School.

Classroom setting

The ELU instruction took place in a biology laboratory. There were sufficient laboratories for all science subjects in this school, with two for biology. The wall was hung with diagrams of animal anatomy and cell division made by students of the previous years. A television connected with a video player was installed in all laboratories. There was no overhead projector because the teachers used a web camera to capture a transparency and an object and display it on the television. However, the quality of picture was poor and too small for the students sitting at the back of the class. There was sufficient scientific equipment in each laboratory. They all were kept clean and orderly. In the Genetics Unit, where the usual teaching strategy was lecturing, the arrangement of seating was in the traditional rows of desks separated by aisles, with all students facing the same direction. However, in Evolution Unit, she changed the arrangement by putting groups of four desks together to accommodate and facilitate group work, discussion and experimentation.

Research Question III: How do the teachers implement the ELU in their own context?

The discussion on this section will be focused on Sarapee’s implementation of the ELU in Pasak School. This section will describe the teaching practice including teaching strategies, the use of instructional media and material, and the assessment technique she employed in the classroom. Classroom interaction was also investigated. At the end of this section, teachers’ conceptual difficulties and awareness of students’ non-scientific ideas are discussed.

Teaching practice

Before implementing the ELU, Sarapee had employed lecturing as a main instructional method for all topics of genetics. When she implemented the ELU for the Evolution Unit, Sarapee followed the instructional guidelines and made use of all instructional media and materials of ELU in the first week of implementation. The students noticed that Sarapee had employed different teaching strategies from what she had done before. In the later weeks, however, it found that the instruction had become more teacher-centered, subject-oriented and hierarchical. The probing questions and classroom discussion suggested in the lesson plans were often skipped. She often told the students the conclusions of the activities or solving the problems for students rather asking them to figure them out on their own.

For example, in Lesson Four, Population at the Equilibrium, Sarapee did not ask students to work in-group to find out the allele and genotypic frequencies of MN blood groups of a given population. Instead, she solved the problem for the students and asked them to record the answers, without discussing the results. Commenting after the lesson, Sarapee said that if she had let the students work on this in groups, she could not have finished the lesson on time because they would have spent so much time on solving the problems. She thought that many of them could not have done the exercise at all and being in a group, they might have played around with their friends.

Sarapee used a variety of methods to assess student knowledge acquisition, including traditional pencil and paper tests, worksheets, discussions with the teacher, group work, and oral and poster presentation. Sarapee collected and marked student worksheets regularly and returned the documents to students. However, she did not discuss their work with the class as a whole, or identify areas for review. Acting on her own initiative, she was the only teacher to assess practical skills. During the Making a Fossil activity, she moved from group to group, observing the students at work and asking questions about the exercise and their involvement in it. She then gave feedback to each group on how well they are working together. A formal observation sheet was used for gathering specific data and grading each group's performance. At the end of the period she shared the results of her observations with the whole class.

Sarapee was afraid that the ELU would not cover the evolutionary topics addressed by the examination and the textbook of former national curriculum (IPST, 1981; revised 1990). She was most concerned about Human Evolution, a topic included in the IPST textbook but not in the ELU. She was certain this topic would be in the coming entrance examination and therefore taught this topic as well as the ELU material, based on material she had accumulated over several years. Sarapee provided practice tests and encouraged the students to use them often, emphasizing that the university exams did not vary much from year to year. Therefore, the more the students practiced, the more likely they were to do well in the examinations.

<u>Classroom interaction</u>

When examining the interaction between the teacher and students, it was found that Sarapee did not encourage a whole class discussion in the classroom. Even when she asked a lot of questions, they called for facts and memorization. The students were not asked to clarify their idea, or provide evidence for their opinions. She likely dominated in the discussion. She asked questions to a few same students all the time. There was no room for other students to propose alternative ideas. To illustrate Sarapee's instruction and classroom environment, the discussion on the differences between allele, gene, genotype, and phenotype is examined as follow.

Sarapee:	Do you still remember "allele, genotype, and phenotype" of the last unit?
Ss:	Yes
Sarapee	Good! Tell me, what is the phenotype? It is the easiest one.
S1:	<u>Things</u> that we can see
Sarapee:	Sort of. Phenotype is a structure, function, and behavior of a living thing. It is <u>observable, measurable and detectable</u> such as eye color, height, ability to roll a tongue (wrote on the board). What about the genotype?
S2:	Symbols like AA, Aa, aa, RRrr
S3:	A and a
S1:	The <u>stuff</u> inside an organism's body. It controls the expression
Sarapee	Not quite. Genotype is the set of genes inherited by an individual. It specifies phenotypes (wrote on the board) for example AA and Aa define for tall while aa defines short. What is the allele?
Ss	(quiet)
Sarapee	Forgot? How come? (pause) Allele is any one of a number

of alternative forms of the same gene occupying a given locus on a chromosome (wrote on the board) such as A and a.

From the dialogue above, Sarapee did not probe her students' understanding of the terms allele, genotype and phenotype as suggested by ELU. She asked the students to recall the definition of these concepts. When they could not do so, she repeated the definitions and asked them to remember. Nor did she clarify students' idea. She did not probe further what S1 meant by *things* and *stuff*, nor asked S3 to elucidate the terms, allele and genotype. She did not check whether they understood her use of the terms *observable, measurable,* and *detectable*.

Teacher's conceptual difficulties and awareness of students' non scientific ideas

Sarapee was not aware of student's non-scientific explanations of the origin of variation. She accepted one student's non-scientific explanation as shown in the following dialogue. This might have strengthened the use of the non-scientific model and created confusion among students who had accepted scientific understanding and made them uncertain about their exiting idea.

Sarapee:	…By the way, you haven't told me yet where the two colors of the frogs come from?
Ss:	(pause)
S3:	Maybe…nature. Nature must have created the variation
Sarapee:	Exactly, the nature gave green and yellow colors to the frogs. What will happen to this population as the time goes by?
Ss:	The yellow will become less and less

In addition, Sarapee was not aware of the different meanings of terms in the everyday and scientific contexts. For example, when discussing the "frogs and egret" material, she and her students used the Thai word "cha-nid" to refer to "a group of the same kind": one student said, "There are two cha-nid of frogs; yellow and green. "Cha-nid" is a problematic word because of its multiple meanings. The word can mean either "a group of the same kind" or "a species" (The Royal Institute of Thailand, 1982). The use of this word in this context is not appropriate because it may lead some students to believe that the two groups of frogs were different species, instead of understanding that the two groups of frogs were different morphs of the same species.

<u>The effect of the implementation of the ELU on a teacher's future teaching practice</u>

Although Sarapee did not always follow the ELU, the positive feedback from the students made her reflect on her teaching practice. In the last weekly meeting, she said she noticed that her students enjoyed doing the activities. They gave more attention to the lessons than ever before, with many positive changes in their behaviors. They had developed a strong sense of responsibility towards their own study and the group. She was delighted with these changes and agreed that giving an opportunity for hands-on and group work could increase student attention and make class more enjoyable.

Implementing the ELU also made her realize the weaknesses of her own students and the problems associated with lecturing as the sole or main teaching method. After the Making a Fossil activity, she commented to the class that she felt very disappointed that so many students could not conduct the exercise properly: "Many of you don't know anything about doing an experiment. You guys don't know how to put out the alcohol lamp, how to set up the equipment. You did not follow the direction. How come you forget these basic things? You all are supposed to know it. More importantly and sadly, you don't know how to work with each other. I am worrying about all of you. At the university level, you will not be able to avoid using this equipment.." This activity let her know that her students lacked science process skills. "The students did not have as much opportunity to do experiments as they did at the lower secondary level", she said. She thought that she would put more emphasis on the science process skills in her teaching and would adopt and adapt some of the ELU activities to teach evolution in the following academic years.

In conclusion, Sarapee used all the ELU materials and instructional media and conducted some of the recommended learning activities. The university entrance examination had a great influence on her beliefs and teaching practices. However, while she did not always follow the lesson plans, allowing time for group work, or exploring student ideas, implementing the ELU allowed her to recognize the changes in student behavior, student difficulties with the material, and the problem of using lecturing as the main teaching method. She started reflecting on effective teaching.

Research Question IV: how does the Evolution Learning Unit (ELU) enhance student understanding of Evolution?

Finding I: After the instruction, there is an increase in the number of students using Neo-Darwinism in the concepts of Role of Variation, Change in a Trait, and Role of Environment. The majority of students consistently use Progressive Creationism to explain Origin of Variation and used Neo-Darwinism and Lamarckism to explain Speciation over pretest and posttest

Origin of Variation

Neo-Darwinism is not the most common model in all contexts in pretest and posttest (Table 6.14). The majority of students preferred Progressive Creationism in bentgrass, moth, E. coli in both pretest and posttest and guppy in pretest. The percentages of students using this model are very high. In bentgrass, moth and *E.coli*, they are all higher than 60 percent. As for finch, most of students, around 85 percent of students in pretest and posttest preferred Lamarckism to other explanatory models.

Table 6.14 The Most Common Model for Each Context of Origin of Variation (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	PROG (64.30)	PROG (72.90)	PROG (43.80)	PROG (62.50)	LAM (85.40)
Post-test	PROG (67.40)	PROG (63.00)	LAM (34.80)	PROG (71.70)	LAM (84.80)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationsim (young earth)

When examining the use of the model of individual students, the results are consistent; the percentages of student who used a non-scientific model in both pretest and posttest (Non-Sci to Non-Sci category) were highest in all contexts (Table 6.15). In moth and guppy, in a particular, the percentages of student using the non-scientific model are 86.97 and 88.90 percent respectively. Among those usinga non-scientific model are the students who employed the same non-scientific model over the two tests which are found the most. This showed that prior models are resistant to change to this group of students. This resistance might come from what they were taught in the classroom. As discussed in classroom interaction, Sarapee did not link the concept of origin of variation while she was teaching the process of natural selection. This might have made students incapable of making a connection between the origin of variation and natural selection.

Table 6.15 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Origin of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(4)	(8.51)	(0)	(0)	(1)	(2.22)	(4)	(8.69)	(14)	(30.43)
(1→ 1)	4	8.51	0	0.00	1	2.22	4	8.69	14	30.43
Scientific to Non –Scientific	(8)	(17.02)	(1)	(2.17)	(2)	(4.44)	(9)	(19.57)	(2)	(4.35)
(1→ 2)	7	14.89	0	0.00	1	2.22	9	19.57	0	0.00
(1→ 3)	1	2.13	1	2.17	0	0.00	0	0.00	0	0.00
(1→ 4)	0	0.00	0	0.00	1	2.22	0	0.00	2	4.35
Non - Scientific to Non - Scientific	(27)	(57.45)	(40)	(86.97)	(40)	(88.90)	(26)	(56.51)	(21)	(45.64)
(2→ 2)	22	46.81	21	45.65	9	20	19	41.30	1	2.17
(2→ 3)	0	0.00	6	13.04	5	11.11	2	4.35	1	2.17
(2→ 4)	0	0.00	2	4.35	4	8.89	1	2.17	1	2.17
(3→ 2)	3	6.38	7	15.23	3	6.67	3	6.52	1	2.17
(3→ 3)	0	0.00	3	6.53	6	13.34	0	0.00	16	34.79
(3→ 4)	0	0.00	1	2.17	5	11.11	0	0.00	0	0.00
(4→ 2)	1	2.13	0	0.00	1	2.22	1	2.17	0	0.00
(4→ 3)	1	2.13	0	0.00	3	6.67	0	0.00	0	0.00
(4→ 4)	0	0.00	0	0.00	4	8.89	0	0.00	1	2.17
Non – Scientific to Scientific	(8)	(17.02)	(5)	(10.86)	(2)	(4.44)	(7)	(15.23)	(9)	(19.58)
(2→ 1)	8	17.02	4	8.69	1	2.22	6	13.06	3	6.52
(3→ 1)	0	0.00	0	0.00	1	2.22	1	2.17	5	10.89
(4→ 1)	0	0.00	1	2.17	0	0.00	0	0.00	1	2.17
TOTAL	47	100	46	100	45	100	46	100	46	100

1 = Neo-Darwinism 2 = Progressive Creationism 3 = Lamarckism 4 = Creationism (Young Earth)

Role of Variation

Neo-Darwinism is the most common model in all contexts in both pretest and posttest. In bentgrass and moth, in a particular, there is a sharp increase in the number of student using the scientific model and a drop in the use of non-scientific models between pretest and posttest (Table 6.16). In moth, for example, the percentage of student using Neo-Darwinism increased in double form 39.69 percent to 76.10 percent while all non-scientific models, Lamarckism, Creationism (young earth) and the idea that variation has no role, decreased by half.

Table 6.16 The Most Common Model for Each Context of Role of Variation (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	NEO	NEO	NEO	NEO
	(47.90)	(39.69)	(39.60)	(83.30)	(80.40)
Post-test	NEO	NEO	NEO	NEO	NEO
	(73.90)	(76.10)	(39.10)	(88.40)	(68.80)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationsim (young earth)

This result is consistent when examined the use of which model in pretest and posttest of individual students (Table 6.17). The number of students using the scientific model encompasses those having science before the instruction (Sci to Sci category) and those changing non-scientific models to the scientific model after the instruction (Non-Sci to Sci category). Unlike the concept of the Origin of Variation, the use of the scientific model over pretest and posttest (Sci to Sci category) is predominant in all contexts except guppy in which the use of non-scientific models in both pretest and posttest (Non Sci to Non-Sci category) is most common. In bentgrass, *E. coli*, and finch, the percentages of the Sci to Sci category are all more than 50 percent. In moth, the percentage of students changing model from non-scientific to scientific is the same as that of those holding the scientific model over pretest and posttest, 34.79 percent. In bengrass and finch, the Non-Sci to Sci category is the second most common by 22.87 and 24.46 percent respectively. For these students, the intervention might enhance their scientific understanding of role of variation.

Table 6.17 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Variation

	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
Use of Models (pre→ post)	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(18)	(51.43)	(16)	(34.79)	(12)	(26.09)	(31)	(65.96)	(25)	(55.55)
(1→ 1)	18	51.43	16	34.79	12	26.09	31	65.96	25	55.55
Scientific to Non –Scientific	(2)	(5.71)	(4)	(8.69)	(5)	(10.87)	(7)	(14.90)	(5)	(11.11)
(1→ 2)	0	0.00	0	0.00	2	4.35	2	4.25	2	4.44
(1→ 3)	2	5.71	4	8.69	2	4.35	4	8.52	0	0.00
(1→ 4)	0	0.00	0	0.00	1	2.17	1	2.13	3	6.67
Non - Scientific to Non - Scientific	(7)	(19.99)	(10)	(21.73)	(24)	(52.18)	(4)	(8.51)	(4)	(8.88)
(2→ 2)	2	5.71	3	6.52	4	8.69	0	0.00	1	2.22
(2→ 3)	0	0.00	3	6.52	0	0.00	1	2.13	0	0.00
(2→ 4)	2	5.71	1	2.17		6.52	0	0.00	2	4.44
					3					
(3→ 2)	0	0.00	0	0.00	2	4.35	0	0.00	0	0.00
(3→ 3)	1	2.86	2	4.35	3	6.52	2	4.25	0	0.00
(3→ 4)	2	5.71	0	0.00	0	0.00	0	0.00	0	0.00
(4→ 2)	0	0.00	1	2.17	4	8.69	1	2.13	0	0.00
(4→ 3)	0	0.00	0	0.00	3	6.52	0	0.00	0	0.00
(4→ 4)	0	0.00	0	0.00	5	10.89	0	0.00	1	2.22
Non – Scientific to Scientific	(8)	(22.87)	(16)	(34.79)	(5)	(10.86)	(5)	(10.63)	(11)	(24.46)
(2→ 1)	8	22.87	7	15.23	1	2.17	2	4.25	6	13.35
(3→ 1)	0	0.00	8	17.39	1	2.17	2	4.25	2	4.44
(4→ 1)	0	0.00	1	2.17	3	6.52	1	2.13	3	6.67
TOTAL	35	100	46	100	46	100	47	100	45	100

1 = Neo-Darwinism 2 = Lamarckism 3 = Creationism (Young Earth) 4 = No Effect…Same Species

Change in a Trait

Neo-Darwinism is the most common model in pretest and posttest in guppy, *E. coli* and finch (Table 6.18). In bentgrass, there is a change in the most common model from Lamarckism to Neo-Darwinism. In this context, the percentage of students using the scientific model increases from 20 percent in pretest to 41.30 percent in posttest. In moth, the most common model is Progressive Creationism in pretest and posttest. However, there is an increase in number of students using Neo-Darwinism by as twice as many.

Table 6.18 The Most Common Model for Each Context of Change in a Trait (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	PROG	NEO	NEO	NEO
	(45.80)	(64.60)	(43.80)	(39.60)	(67.40)
Post-test	NEO	PROG	NEO	NEO	NEO
	(41.30)	(67.40)	(34.80)	(43.50)	(58.30)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

When look at the use of models between pretest and posttest of individual students (Table 6.19), the consistent use of non-scientific models over the two tests (Non-Sci to Non-Sci category) is the most common in all contexts except finch. In finch, 50 percent of students used Neo-Darwinism (Sci to Sci category) in pretest and posttest which Non-Sci to Non-Sci category is in the third rank as Non-Sci to Sci category. In bentgrass, moth and *E.coli*, Non-Sci to Sci category is the second common category with 32.62, 23.90, and 22.22 percent respectively.

Table 6.19 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Change in a Trait

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(4)	(8.69)	(2)	(4.35)	(9)	(20)	(9)	(20)	(23)	(50)
(1→ 1)	4	8.69	2	4.35	9	20	9	20	23	50
Scientific to Non –Scientific	(6)	(13.04)	(2)	(4.35)	(13)	(28.89)	(10)	(22.22)	(5)	(10.87)
(1→ 2)	0	0.00	0	0.00	2	4.45	1	2.22	0	0.00
(1→ 3)	3	6.52	2	4.35	7	15.55	4	8.89	2	4.35
(1→ 4)	3	6.52	0	0.00	4	8.89	5	11.11	3	6.52
Non - Scientific to Non - Scientific	(21)	(45.65)	(31)	(67.40)	(16)	(35.56)	(16)	(35.56)	(9)	(19.56)
(2→ 2)	0	0.00	1	2.17	0	0.00	0	0.00	0	0.00
(2→ 3)	0	0.00	0	0.00	0	0.00	0	0.00	1	2.17
(2→ 4)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
(3→ 2)	0	0.00	0	0.00	2	4.45	1	2.22	0	0.00
(3→ 3)	4	8.69	23	50.2	5	11.11	3	6.66	3	6.52
(3→ 4)	6	13.05	1	2.17	4	8.89	5	11.13	1	2.17
(4→ 2)	1	2.17	0	0.00	0	0.00	0	0.00	0	0.00
(4→ 3)	5	10.87	5	10.89	3	6.66	3	6.66	2	4.35
(4→ 4)	5	10.87	1	2.17	2	4.45	4	8.89	2	4.35
Non – Scientific to Scientific	(15)	(32.62)	(11)	(23.9)	(7)	(15.55)	(10)	(22.22)	(9)	(19.57)
(2→ 1)	0	0.00	1	2.17	0	0.00	0	0.00	0	0.00
(3→ 1)	7	15.23	7	15.21	3	6.66	2	4.44	8	17.40
(4→ 1)	8	17.39	3	6.52	4	8.89	8	17.78	1	2.17
TOTAL	46	100	46	100	45	100	45	100	46	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Progressive Creationism 4 = Lamarckism

Role of Environment

The student used Neo-Darwinism the most to explain Role of Environment in pretest and posttest in all contexts except *E.coli*. In *E. coli,* the student preferred Lamarckism in both pretest and posttest by 47.90 and 45.70 percent respectively (Table 6.20). The percentages of students using Neo-Darwinism in bentgrass, moth, guppy and finch are very high by more than 50 percent. The increase in number of students using the scientific model is found in moth from 47.90 percent in pretest to 69.60 percent in posttest.

Table 6.20 The Most Common Model for Each Context Role of Environment (%)

Tests	Contexts				
	bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	NEO	NEO	LAM	NEO
	(70.80)	(47.90)	(75.00)	(47.90)	(72.90)
Post-test	NEO	NEO	NEO	LAM	LAM
	(52.20)	(69.60)	(56.50)	(45.70)	(58.70)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationsim (young earth)

From the examination of the use of model between pretest and posttest of individual students (Table 6.21), the great number of students using the scientific model consist of those having this model before attending evolution class (Sci to Sci category) and those changing non-scientific models to the scientific one after receiving the instruction (Non-Sci to Sci category). Sci to Sci category, in a particular, is found the most in all contexts except E. coli which the majority used non-scientific model over pretest and posttest by 66.67 percent. The percentages of Sci to Sci category range from 32.62 to 44.44 percent. To this group of student, the instruction might have reinforced their scientific understanding of this concept. The percentages of Non-Sci to Sci category of all contexts are also significant, although it is not the most common in all contexts; around 20 percent in bentgrass and guppy, 32.62 percent in moth, and around 16 percent in *E. coli* and finch.

Table 6.21 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Environment

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(18)	(39.13)	(15)	(32.61)	(18)	(40)	(2)	(4.44)	(20)	(44.44)
(1→ 1)	18	39.13	15	32.61	18	40	2	4.44	20	44.44
Scientific to Non –Scientific	(13)	(28.26)	(8)	(17.39)	(14)	(31.2)	(6)	(13.33)	(12)	(26.68)
(1→ 2)	6	13.04	0	0.00	3	6.67	1	2.22	2	4.44
(1→ 3)	2	4.35	6	13.04	5	11.11	5	11.11	10	22.24
(1→ 4)	5	10.87	2	4.35	6	13.33	0	0.00	0	0.00
Non - Scientific to Non - Scientific	(6)	(13.04)	(8)	(17.38)	(4)	(8.90)	(30)	(66.67)	(6)	(13.33)
(2→ 2)	2	4.35	0	0.00	0	0.00	3	6.67	1	2.22
(2→ 3)	0	0.00	0	0.00	0	0.00	6	13.34	0	0.00
(2→ 4)	0	0.00	0	0.00	2	4.45	0	0.00	0	0.00
(3→ 2)	0	0.00	0	0.00	0	0.00	9	20	0	0.00
(3→ 3)	1	2.17	6	13.04	2	4.45	10	22.22	4	8.89
(3→ 4)	2	4.35	1	2.17	0	0.00	2	4.44	0	0.00
(4→ 2)	0	0.0	0	0.00	0	0.00	0	0.00	0	0.00
(4→ 3)	0	0.00	1	2.17	0	0.00	0	0.00	1	2.22
(4→ 4)	1	2.17	0	0.00	0	0.00	0	0.00	0	0.00
Non – Scientific to Scientific	(9)	(19.57)	(15)	(32.62)	(9)	(19.99)	(7)	(15.56)	(7)	(15.55)
(2→ 1)	2	4.35	0	0.00	1	2.22	4	8.89	2	4.44
(3→ 1)	2	4.35	13	28.27	3	6.66	3	6.67	4	8.89
(4→ 1)	5	10.87	2	4.35	5	11.11	0	0.00	1	2.22
TOTAL	46	100	46	100	45	100	45	100	45	100

1 = Neo-Darwinism 2 = Dominant/Recessive Genes 3 = Lamarckism 4 = Creationism (Young Earth)

Speciation

There are two most common models used to explain Speciation (Table 6.22), Neo-Darwinism and Lamarckism. In moth and guppy, the most common model in pretest and posttest is Neo-Darwinism. In these two contexts, the percentages of students using the scientific model increase; 47.90 to 67.49 percent in moth and 37.50 to 50 percent in guppy while the percentages of all non-scientific models decrease. In bentgrass, the most common model shifts from Lamarckism to Neo-Darwinism. In this context, the percentage of students using Lamarckism drops from 45.80 to 19.60 percent. Lamarckism is the most common model in *E.coli* and finch in both pretest and posttest by more than 45 percent.

Table 6.22 The Most Common Model for Each Context of Speciation (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	NEO	NEO	LAM	LAM
	(45.80)	(47.90)	(37.50)	(60.40)	(77.10)
Post-test	NEO	NEO	NEO	LAM	LAM
	(39.10)	(67.40)	(50.00)	(45.70)	(76.10)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

When examine the use of model between pretest and posttest of individual students (Table 6.23), Non-Sci to Non-Sci category is found the most in all contexts. In Bentgrass, *E. coli* and finch, in a particular, the percentages of this category is higher than 50 percent. Non-Sci to Sci category is in the second place in the rank order in all contexts except moth whose percentage is less than that of Sci to Sci by two percent.

Table 6.23 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Speciation

	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
Use of Models (pre→ post)	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(9)	(19.57)	(12)	(28.57)	(11)	(23.92)	(2)	(5.41)	(2)	(4.16)
(1→ 1)	9	19.57	12	28.57	11	23.92	2	5.41	2	4.16
Scientific to Non –Scientific	(3)	(6.52)	(2)	(4.76)	(6)	(13.04)	(4)	(10.82)	(0)	(0.00)
(1→ 2)	1	2.17	0	0.00	3	6.52	0	0.00	0	0.00
(1→ 3)	0	0.00	0	0.00	0	0.00	2	5.41	0	0.00
(1→ 4)	2	4.35	2	4.76	3	6.52	2	5.41	0	0.00
Non - Scientific to Non - Scientific	(24)	(52.18)	(17)	(40.47)	(18)	(39.14)	(25)	(67.56)	(41)	(85.41)
(2→ 2)	2	4.35	7	16.66	3	6.52	0	0.00	2	4.16
(2→ 3)	1	2.17	2	4.76	0	0.00	1	2.70	3	6.25
(2→ 4)	2	4.35	3	7.14	1	2.18	0	0.00	0	0.00
(3→ 2)	0	0.00	0	0.00	3	6.52	2	5.41	4	8.32
(3→ 3)	9	19.57	1	2.38	3	6.52	9	24.32	24	52.08
(3→ 4)	7	15.23	1	2.38	3	6.52	8	21.62	3	6.25
(4→ 2)	1	2.17	0	0.00	1	2.18	0	0.00	0	0.00
(4→ 3)	1	2.17	3	7.14	1	2.18	5	13.51	5	10.41
(4→ 4)	1	2.17	0	0.00	3	6.52	0	0.00	0	0.00
Non – Scientific to Scientific	(10)	(21.73)	(11)	(26.19)	(11)	(23.9)	(6)	(16.21)	(5)	10.41
(2→ 1)	2	4.35	8	19.04	1	2.17	0	0.00	3	6.25
(3→ 1)	4	8.69	1	2.38	6	13.04	2	5.41	2	4.16
(4→ 1)	4	8.69	2	2.38	4	8.69	4	10.80	0	0.00
TOTAL	46	100	42	100	46	100	37	100	48	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Lamarckism 4 = Mutation

Finding II: To explain evolutionary process, the students did not hold a single model in their mind. They instead hold many and apply the one that most reasonable, to them, for a particular context and concept and this is consistent in both pretest and posttest.

Contexts and concepts affected the use of models of students. This is consistent in pretest and posttest. When examine the percentage of particular models across varying contexts (table 6.24 by columns), the students did not use only one model to explain a concept of evolution as the most common models varies across different contexts. To students, one model is preferable than other models for a particular context. In the concept origin of variation, for example, in posttest, Progressive Creationism is the most common model in bentgrass, moth, guppy and *E. coli* but it is not in Finch. In finch, Lamarckism is most preferred. Similarly, in speciation, the majority of students used Neo-Darwinism in bentgrass, moth, and guppy and preferred Lamarckism in the other two contexts, *E.coli* and finch. Not only the use of model is determined by the contexts of question, but it is affected by the concept the students are dealing with. For a particular concept, one model is more suitable than others. When examined the percentage of particular models across different concepts (table 6.24 by rows), the most common model are not the same. In context of *E. coli*, for example, the majority of students used Progressive Creationism in origin of variation, Neo-Darwinism in role of variation and change in a trait, and Lamarckism in role of environment and speciation.

Table 6.24 The Percentages Of Pasak Students Using a Particular Model between Pretest and Posttest to Explain Various Concepts of Evolution across Five Contexts of Questions

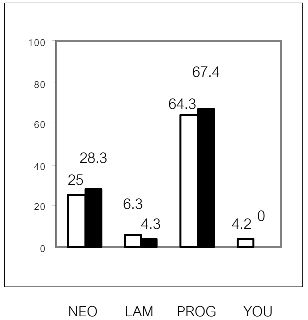
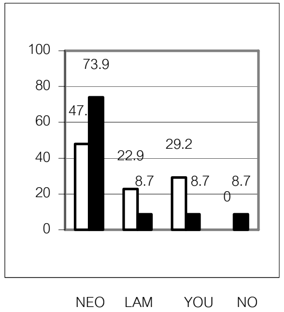
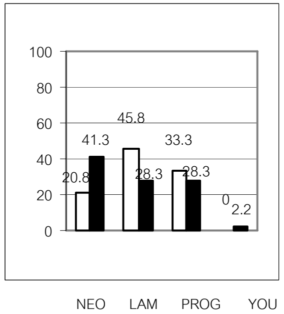
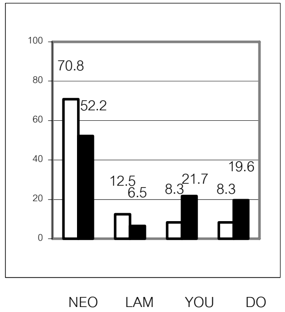
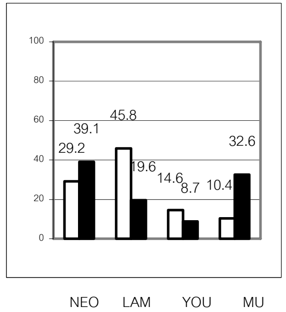
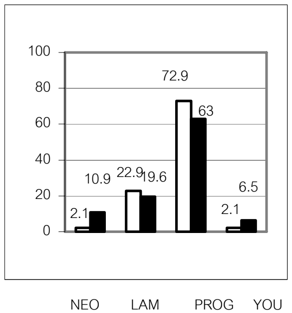
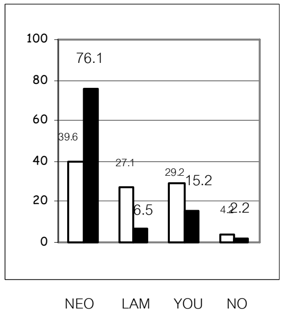
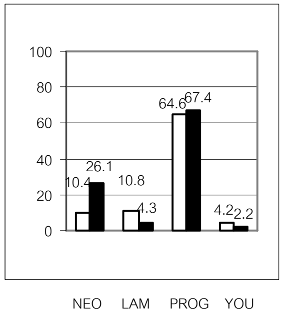
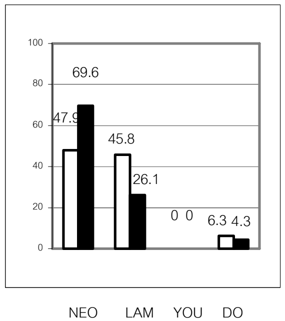
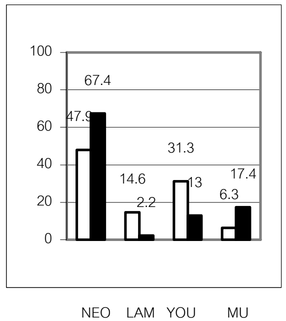
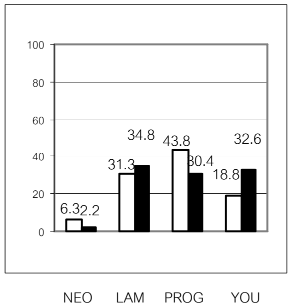
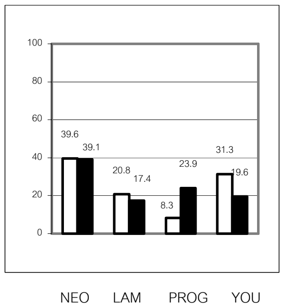
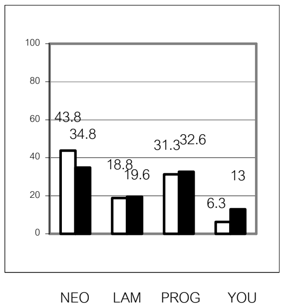
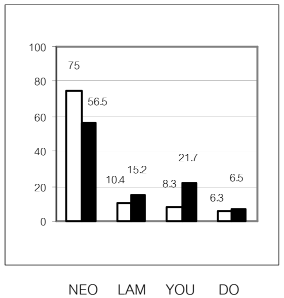
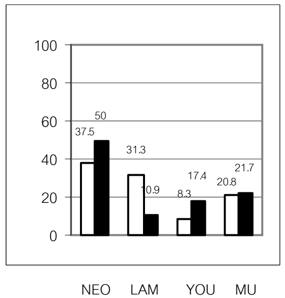
Concepts / Contexts	Origin of Variation	Role of Variation	Change in a Trait	Role of Environment	Speciation
Bentgrass					
Moth					
Guppy					

Table 6.24 (Cont'd)

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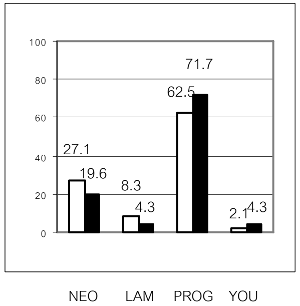
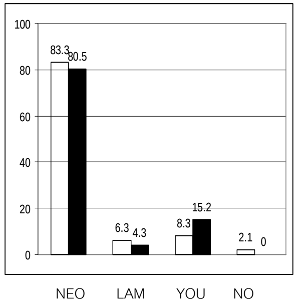
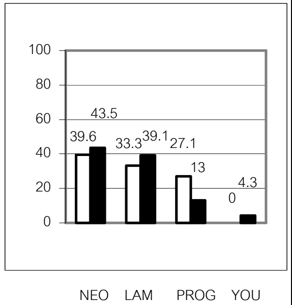
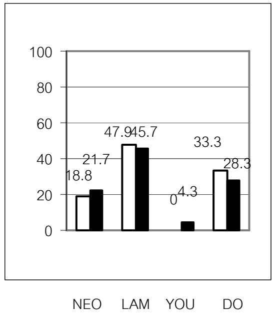
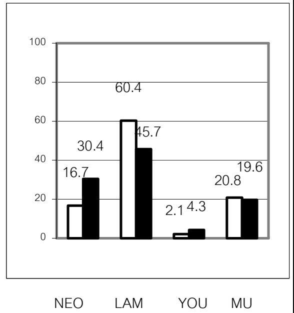
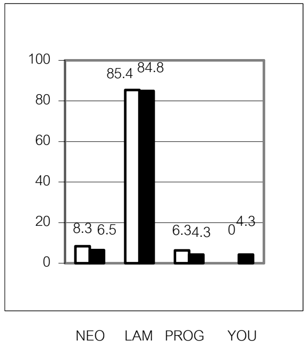
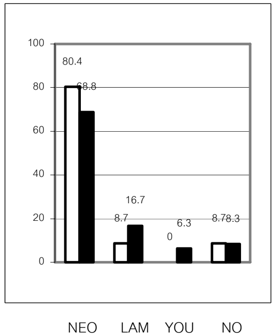
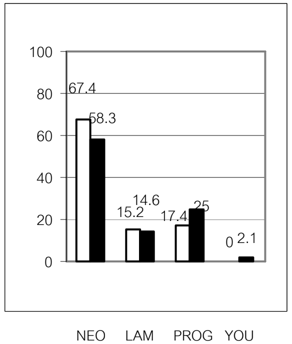
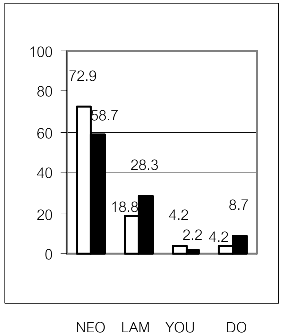
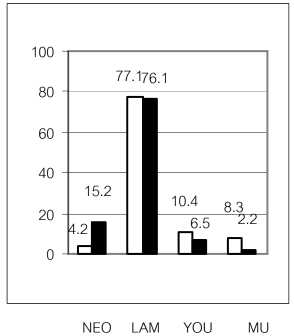
<tr><td>E. coli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td></tr>
<tr><td>Finch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td></tr>
<tr><td colspan="6">□ = Pretest ▮ = Posttest
NEO = Neo-Darwinism LAM = Lamarckism PROG = Progressive Creationism YOU = Creationism (Young Earth) MU = Mutation
NO = Variation has no effect</td></tr>
</table>

In-depth interviews were conducted to investigate the reason behind the insistent use of model across contexts and concepts. Five students whose answers showed inconsistency in use of models over the varying contexts were drawn out for the in-depth interviews. From the test results, in the concept of change in a trait, a number of students preferred Progressive Creationism in moth but Lamarckism in *E. coli*. One student gave reasons of his explanation as follows.

R: Why did you pick up this (the statement of Progressive Creationism) for this situation (industrial melanism in moth)?

Anan: I think it was most possible one. The toxic in the air at that time might induce the light-colored moths to change their form.

R: How did it change, you think?

Anan: It was probably a mutation. The white moth mutated into the dark one.

R: Can you elaborate on that?

Anan: When exposed the chemicals, they suddenly changed their body systems. These moths later gave rise all dark colored offspring.

R: How did the light color first occur in the population of peppered moth?

Anan: I think it was already with the moth at the beginning.

R: What do you think about this statement (point to the statement of Lamarckism)?

Anan: I don't think it is the right one. If it were so, there would be various kinds of moths. I mean many shades of color.

R: Let's move to the *E. coli* situation. Why did you choose this (the statement of Lamarckism)?

Anan: Ah…OK. I have heard that when germs invaded the body, our immune system would automatically produce antibody to

> fight the disease. This takes time. The body produced the antibody bit by bit. In this case, I think, like human, the bacteria (*E. coli*) needs to prevent themselves from chemicals (antibiotic) by the same process.

From the dialogue, Anan thought like Sutat, a Karnika's student of the first case study. It is logical to him to explain the change a microscopic and physiological trait by Lamarckism and the change of a macroscopic and morphological trait by Progressive Creationism. For other four students, they could not give reasons for their explanations. They only said that the choice they had made for each context more possible than others to happen in the real situation.

In conclusion, the students held scientific models of some evolutionary concepts after instruction; role of environment, change in a trait and role of Environment. To these students, the instruction might have encouraged the students to change the models from non-scientific to scientific and reinforce the scientific model of the students who had already had this model. However, like the case of Karnika, the majority of Sarapee's students still had difficulty in the concepts of origin of variation and speciation. This might be the result of the instruction. From the dialogue on the adaptation of frog skin color, Sarapee referred to the concept of origin of variation by asking the class to explain how the green and yellow skin color first occur in a population as suggested in the lesson plan. However, Sarapee allowed only one student to answer and she immediately accepted that student's non-scientific explanation, Creationism, without question. This could have reinforced the non scientific model in some students and confused those holding the scientific model. Students' view on these two concepts were not elicited and corrected by the teacher during teaching process. As for speciation, like Karnika, Sarapee did not follow ELU activities. In stead, she summarized only the key ideas from textbook and asked the students to take note. By this mode of learning, the students were asked remembered the definitions of terms without truly understanding them. The difficulties in understanding the concepts of origin of variation and speciation identified from testing might have been the consequence of the instruction.

Case Study Three: Nanfah School (1)

School Context

Nafah School located in a district of Bangkok. The school is a public, co-educational school with more than 3000 students. There were twelve classes of each grade of lower secondary level; 50-52 students per class and ten classes for each grade of upper secondary level with 40 students. The school was popular among locals in that area since it has a great number of students gaining places in public universities. The school was established in 1992; it is the youngest school in this study. At the time this research was conducted, the school had been operating for twelve years. The school facilities were fully equipped and still in very good condition. The school was all given good and continuous financial support by parents' association. The school allocated this fund for the benefit of education, welfare and a healthy community within the school. The majority of students came from middle and upper class family. Ninety-eight percent of students were Buddhist. The rest encompassed Christian and Muslim. The upper secondary students were provided with four optional study programs to concentrate on; English and French or Japanese, English and Mathematics, Mathematics and Science and Vocational Studies. There were eighteen weeks in one semester; sixteen for teaching and other two weeks for examination sessions. The study hour lasted for fifty minutes. At the time the ELU was implemented, the school still used the former curriculum for Grade 12 students but was planning to implement a school-based curriculum in the following year.

Teacher and Student Background

In previous years, there had been only one grade 12 biology teacher who was Ms. Soyfah but in academic year 2004, she was assigned to teach Advanced Biology to grade 10 students. She was replaced by Grade 10 teacher, Mrs. Pinsuda who had never taught Grade 12 Biology before. Pinsuda was fifty years old and got B.Ed. in Teaching Science from a teacher college. She was a new teacher of Nanfah school. She had just come to this school for a year. She taught lower secondary science and

Grade 10 Biology (taxonomy and ecology) at another school for more than twenty years. She had never taught genetics and evolution of Grade 12 Biology. When she was assigned to teach these two topics, she was very worried about the content. She always asked Soyfah and a student teacher who had a B.Sc in Biology to explain to her about the concepts and sometimes helped her teach some concepts to students.

Pinsuda implemented the ELU in three classes; high, average and low ability. There were 121 students in total; 57 males and 64 females. Eighty nine percent of students are 17-18 years of age. Seventy four percent of students had GPA lower than 3.00 in a four grading system. The grading system reflects a 4-point scale; grade 4 (Excellent), grade 3 (Above Average), grade 2 (Average), Grade 1 (Below Average), and Grade 0 (Failure). Forty nine percent of students got grade 2 (Average) in Grade 12 Biology of the last semester, 31 percent got grade 3 (Above Average), 5 percent got grade 4 (Excellent) and 15 percent was of the combination of grade 1 (Below Average) and 0 (Failure). Seventy eight percent of the students had decided not to use Biology for the entrance examination.

Classroom setting

The teaching took place in a biology laboratory. Nanfah had many science laboratories. Two of them were used for Biology. The laboratory was fully equipped and also had a preparation room for storing chemicals and scientific apparatus. The scientific apparatus were kept orderly and clean. Next to the biology laboratory, was a science learning center. This center provided science learning resources for the students. In the center, the students had access to numerous science textbooks, magazines, science fiction, posters, and internet. The center was fully equipped with multimedia such as a video player, televisions, and a projector. Both Pinsuda and Soyfah used this center for teaching evolution in the second lesson of the ELU. She played the video about the adaptation of animals and plants in mangrove forests to students.

Research Question III: How do the teachers implement the ELU in their own context?

This section discusses the implementation of the ELU in 3 classes of Grade 12 students of Nanfah School by Pinsuda. The section describes her teaching practice including teaching strategy, use of instructional media and material, and assessment technique. The classroom interaction was also investigated. At the end of this section, the discussion will be encompassed the teacher's conceptual difficulties and awareness of students' non-scientific ideas and the effect of the implementation of the ELU on teacher' future teaching practice.

Teaching practice

Pinsuda made a major attempt to follow the instructional guidelines of the ELU. She had tried so hard to repeat all steps in the lesson plan. However, she faced a lot of difficulties in teaching because of her limitation of content knowledge. Although Pinsuda asked all questions in the lesson plan, she did not response to students' answer and could not deal with conceptual conflict during the discussion. She could not run some activities because she was unclear about the concepts. She often told students the answers and conclusions, not letting them engage in discussion and arrive at conclusion on their own. Her instruction, therefore, focused on transmission of knowledge rather than enhancing student understanding of the concept.

This was evident by classroom observation. In Lesson Six: speciation, according to the lesson plan, Pinsuda was supposed to first ask students what "species" meant to them since this word was often and widely used in media to mean different things. The students might have understood it in various ways. However, Pinsuda read the definition of species from the lesson plan to the students and asked them to take note. Another example of this is when she used the picture of Archaeopteryx to give evidence for evolution in Lesson Two. She showed the picture and told the students that Archaeopteryx was part bird and part dinosaur. She did not ask students to observe, describe its features and compare it with the modern-day birds. She only said that Archaeopteryx was an evidence for evolution and did not explain how it supported the notion of descent from common ancestry.

Pinsuda did not use integrated methods to assess student learning. She employed only testing which was administered once at the end of the instruction for the purpose of evaluation of performance and assignment of grades. Even though she asked students to do many exercises, she did not give them feedback. She did not check students' conceptual difficulties and correct their misunderstanding. Pinsuda just gave them the right answers from the answer key in the lesson plan.

Classroom interaction

Pinsuda did not have much interaction with the students. She often dominated the discussion. There were a few students who were given an opportunity to participate in the discussion. These students always dominated the class and were given a lot of attention by the teacher. She did not gather the ideas from other students. Even if she asked students questions, many of which were asked for fact and memorization not probing for student understanding. Sometimes, she used leading questions as shown in the following discussion on the adaptation of frog skin color.

Pinsuda: You can see here (point at the transparency) that there are two populations of frogs in this picture. We know that in any environments, there are always predators and prays. In this case as well, make a prediction, what would happen to these two populations in five years time?

S1: The yellow will become less.

Pinsuda: Right, it will. Why?

S1: They can not adapt to the environment.

Pinsuda: Do you think who can easily detect the yellow frogs?

Ss: The egrets

Pinsuda: Under this condition, in the next ten years, there will be only green frogs in nature. Do you know whose theory this situation is consistent with?

S1: Darwin

Pinsuda: What is his theory called?

Ss: Natural selection

Pinsuda: Excellent!! In a natural setting, the animals who can adapt to the current environment will increase in number while those without the adaptation will be eliminated and finally, disappear from the population.

From the dialogue, Pinsuda mostly used factual questions such as "what is his theory called?", "Do you know whose theory this situation is consistent with. She rarely used questions for higher order thinking asking the students to validate his or her ideas by giving supportive evidence. She employed a leading question to suggest the desired answer: "we know that in any environments, there are always predators and preys. In this case as well, make a prediction, what would happen to these two populations in five years time?". She had clued them on the relationship between frogs and egrets that it was predator and prey. Another leading question was "Do you think who can easily detect the yellow frogs?". This implies the students that the yellow frogs were not natural to the existing environment. .

Teacher's conceptual difficulties and awareness of students' non scientific ideas

Pinsuda had difficulties in teaching some evolutionary concepts. During the discussion in classroom interaction section, Pinsuda did not mention about the cause of variation (origin of variation) of frog skin colors. She did not ask students how the two colors came from. In fact, she had taught it in Genetics Unit in the in topic Genetic Variation. She might not have herself seen the connection between this concept and the process of natural selection of which the origin of variation was the component, the input, of natural selection process. Additionally, she had difficulties in understanding many fundamental concepts of evolution; mostly related to genetics such as population, allele, genotype and phenotype as shown as follows.

Pinsuda: What is a genetic character?

S1: A heritable characteristic.

Pinsuda: Can you give me some examples?

S1: Skin color, hair style

Pinsuda: OK. Tall and short is a good example of the genetic character. A tall man is controlled by gene T while a short guy by t (write on the board). Hair styles; straight or curly that you have just said is also controlled by….

Ss: Genes

Pinsuda: Yes. But the gene are….are what?

S1: Countless

Pinsuda: Yeah…. Tall and short are controlled by T and t (pause). We call these (T and t) alleles. Genes control alleles (T and t), right?

Ss: Yes

Pinsuda: (Write T and t on the board again). This is one allele (point to T) and this is the other one (point to t). Genotypes are what it shows, in this case, tall or short. Phenotype is a symbol like T, t, and TT.

From the dialogue, Pinsuda was confused about gene, allele, genotype, and phenotype. For example, she thought genotype was phenotype and vice versa. This is inconsistent with the scientific conception that the phenotype is the outward, physical appearance of the organism while the genotype is the internally coded, inheritable information carried by the organism.

Pinsuda did not explain to the students the calculation of allele and genotypic frequencies and Hardy-Weinberg principle. For example, in Lesson Four, Population at Equilibrium, she was supposed to work out the allele and genotypic frequencies of Hemoglobin of a given population with students. Instead, she had assigned students to do this exercise as homework. When the students came to the class the period after, the solving method had already been put right on the blackboard. It was the repetition of the answer key in the lesson plan. Pinsuda did not explain it but asked students to take notes. She did not conclude if the populations the students were working on were evolving.

<u>The effect of implementation of the ELU on teacher's future teaching practice</u>

Although Pinsuda had difficulty in understanding the content of evolution, the implementation of the ELU had helped her develop an understanding of evolution. In one weekly meeting, Pinsuda said that since she got through the ELU and attended the meeting, she had gradually developed her understanding of evolution. The meeting let her know what points that she had misunderstood and got an idea how to make students understand a concept scientifically. She said she had got a lot of ideas to teach evolution for the following years. She said that she would definitely continue using the ELU in the following academic years. She thought she would do better since she had had the experience of using it. She would study the teacher manual more.

In conclusion, Pinsuda used the ELU materials to guide her in teaching evolution. However, she had faced difficulties in teaching because of her limitation of knowledge of evolution and genetics. She could not explain some evolutionary concepts, have a hard talk about the concept in the discussion, and give feedback to students' explanation. However, the implementation of the ELU and regular attendance at weekly meetings helped the teacher develop an understanding of evolution and acquire the method of how to teach evolution with more confidence in the future.

<u>Research Question IV: how does the Evolution Learning Unit (ELU) enhance students understanding of Evolution.</u>

Finding I: After the instruction, there is an increase in the number of students using Neo-Darwinism in the concepts of role of variation and role of environment. The students had difficulty in understanding origin of variation and speciation. As for changes in a trait, the students inconsistently used scientific and non-scientific models over different contexts.

<u>Origin of variation</u>

Neo-Darwinism is not the most common model in all contexts in pretest and posttest except *E. coli* and finch in pretest (Table 6.25). The majority of students preferred to use Progressive Creationism and Lamarckism to explain the origin of variation. In bentgrass, moth, in both pretest and posttest, and *E. coli* in posttest, the percentage of students using Progressive Creationism is 40 percent, the highest compared with other models. Lamarckism was used for the most part in guppy in pretest and finch in posttest by more than 30 percent. In guppy, there was shift between non-scientific models from Lamarckism to Creationism (young earth). In *E. coli* and finch, the most common model was changed from the scientific model to non-scientific; Progressive Constructivism (46.30 percent) and Lamarckism (38.80 percent) respectively.

Table 6.25 The Most Common Model for Each Context of Origin of Variation (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	PROG	PROG	LAM	NEO	NEO
	(41.90)	(54.70)	(33.30)	(42.70)	(30.80)
Post-test	PROG	PROG	YOU	PROG	LAM
	(47.90)	(51.20)	(34.70)	(46.30)	(38.80)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism,
YOU = Creationism (young earth)

When examining the use of a model by individual students, the results are consistent (Table 6.26). The percentage of students using the non-scientific model over pretest and posttest (Non-Non category) is highest in all contexts; 47 percent in bentgrass, 78.90 percent in moth, 78.42 percent in guppy, 38.38 percent in *E. coli* and 51 percent in finch. It was also found that in this category, the proportion of students consistently using the same non-scientific model over the two tests were the most prevalent. In moth, for example, among 78.90 percent of Non-sci to Non-sci model holders are 32.11 percent of the students who used Creationism (Gradualism) over pretest and posttest. Interestingly, the percentage of students changing the models from scientific to non-scientific (Sci to Non- sci category) was found in the second rank next to Non- sci to Non- sci category. There were a number of students who changed their scientific model to non-scientific model. This might be the result of instruction that did not focus the scientific model of origin of variation. From classroom discussion as reported in the classroom interaction section, the teacher did not ask the students about the causes of genetic variation. For those who had already held the scientific model, their existing understanding had not been confirmed and reinforced by the teacher. The retention of the scientific model was eventually reduced.

Table 6.26 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Origin of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(11)	(11)	(3)	(2.75)	(1)	(0.98)	(15)	(15.15)	(8)	(8)
(1→ 1)	11	11	3	2.75	1	0.98	15	15.15	8	8
Scientific to Non –Scientific	(30)	(30)	(10)	(9.17)	(12)	(11.77)	(27)	(27.27)	(27)	(27)
(1→ 2)	21	21	7	6.42	4	3.93	21	21.21	8	8
(1→ 3)	5	5	3	2.75	5	4.90	4	4.04	16	16
(1→ 4)	4	4	0	0.00	3	2.94	2	2.02	3	3
Non - Scientific to Non - Scientific	(47)	(47)	(86)	(78.9)	(80)	(78.42)	(38)	(38.38)	(51)	(51)
(2→ 2)	19	19	35	32.11	9	8.82	17	17.17	8	8
(2→ 3)	10	10	10	9.17	10	9.80	3	3.03	6	6
(2→ 4)	2	2	8	7.34	9	8.82	1	1.01	2	2
(3→ 2)	7	7	11	10.09	18	17.64	7	7.07	10	10
(3→ 3)	5	5	9	8.26	5	4.90	7	7.07	14	14
(3→ 4)	0	0.00	0	0.00	8	7.84	1	1.01	2	2
(4→ 2)	4	4	5	4.59	1	0.98	1	1.01	3	3
(4→ 3)	0	0.00	3	2.75	7	6.86	1	1.01	5	5
(4→ 4)	0	0.00	5	4.59	13	12.76	0	0.00	1	1
Non – Scientific to Scientific	(12)	(12)	(10)	(9.18)	(9)	(8.83)	(19)	(19.20)	(14)	(14)
(2→ 1)	7	7	5	4.59	5	4.91	8	8.08	1	1
(3→ 1)	5	5	4	3.68	3	2.94	10	10.11	9	9
(4→ 1)	0	0.00	1	0.91	1	0.98	1	1.01	4	4
TOTAL	100	100	109	100	102	100	99	100	100	100

1 = Neo-Darwinism 2 = Creationism (Gradualism) 3 = Lamarckism 4 = Creationism (Young Earth)

Role of variation

Neo-Darwinism is the model chosen most by students in pretest and posttest in all contexts except guppy (Table 6.27). In guppy, the majority of students preferred Creationism (young earth) to other models by 33.30 and 28.10 percent in pretest and posttest respectively. The increase in number of students using the scientific model was found in the contexts of moth, *E. coli* and finch.

Table 6.27 The Most Common Model for Each Context of Role of Variation (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO (43.60)	NEO (37.60)	YOU (33.30)	NEO (46.20)	NEO (48.70)
Post-test	NEO (40.50)	NEO (44.60)	YOU (28.10)	NEO (53.70)	NEO (54.50)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

When examine the use of models between pretest and posttest of individual students (Table 6.28), it found that the great number of students using the scientific model in posttest encompasses the students who had already had the scientific model since the pretest (Sci to Sci category) and those had changed their non-scientific models to the scientific model (Non-sci to Sci category) after instruction. In *E. coli* and finch, Sci to Sci category is the most common while in other contexts Non-Sci to Non-Sci category is found the most. Interestingly, there were a number of students changing their non scientific models to scientific model in all contexts (Non-Sci to Sci category); 22 percent in bentgrass, 28 percent in moth, 19.90 percent in guppy, 28.45 percent in *E.coli*, and 26.55 percent in finch. To these students, the instruction might have enhanced their understanding of the scientific model of role of variation.

Table 6.28 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(25)	(25)	(21)	(21)	(5)	(4.95)	(30)	(29.41)	(28)	(28.57)
(1→ 1)	25	25	21	21	5	4.95	30	29.41	28	28.57
Scientific to Non –Scientific	(20)	(20)	(16)	(16)	(15)	(14.85)	(14)	(13.72)	(16)	(16.32)
(1→ 2)	3	3	6	6	6	5.94	8	7.84	7	7.14
(1→ 3)	8	8	7	7	3	2.97	5	4.90	4	4.08
(1→ 4)	9	9	3	3	6	5.94	1	0.98	5	5.10
Non - Scientific to Non - Scientific	(33)	(33)	(35)	(35)	(61)	(60.39)	(29)	(28.42)	(28)	(28.56)
(2→ 2)	2	2	7	7	8	7.92	8	7.84	9	9.18
(2→ 3)	1	1	7	7	5	4.95	3	2.94	2	2.04
(2→ 4)	0	0.00	4	4	5	4.95	4	3.92	4	4.08
(3→ 2)	4	4	4	4	7	6.93	1	0.98	2	2.04
(3→ 3)	10	10	3	3	13	12.87	1	0.98	1	1.02
(3→ 4)	7	7	0	0	9	8.91	0	0.00	2	2.04
(4→ 2)	1	1	6	6	5	4.95	4	3.92	4	4.08
(4→ 3)	6	6	2	2	6	5.94	6	5.88	1	1.02
(4→ 4)	2	2	2	2	3	2.97	2	1.96	3	3.06
Non – Scientific to Scientific	(22)	(22)	(28)	(28)	(20)	(19.9)	(29)	(28.45)	(26)	(26.55)
(2→ 1)	7	7	8	8	7	6.94	16	15.69	15	15.31
(3→ 1)	12	12	14	14	5	4.95	6	5.89	5	5.11
(4→ 1)	3	3	6	6	8	7.92	7	6.87	6	6.13
TOTAL	100	100	100	100	101	100	102	100	98	100

1 = Neo-Darwinism 2 = Lamarckism 3 = Creationism (Young Earth) 4 = No Effect…Same Species

<u>Change in a trait</u>

The students did not use a particular model the most across different contexts (Table 6.29). In bentgrass, the majority of students preferred Lamarckism in pretest (39.30 percent) and Progressive Creationism in posttest (35.50 percent). In moth, the students used Progressive Creationism the most by 49.60 percent in pretest and 51.20 percent in posttest. In guppy, the most common model is shifted form Progressive Creationism to Neo-Darwinism. In this context, there is an increase in the percentage of students using the scientific model by 20 percent while those of non-scientific models all drop noticeably. The shift of model towards the scientific model is also found in the context of *E. coli* where the majority of students preferred Lamarckism in pretest but Neo-Darwinism in posttest. However, the percentage of students holding the scientific model in posttest (34.70 percent) is close to that of Lamarckism (32.20 percent). In finch, the students used Neo-Darwinism the most over pretest and posttest by 36.80 and 49.60 percent respectively.

Table 6.29 The Most Common Model for Each Context of Change in a Trait (%)

	Contexts				
Tests	bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	PROG	PROG	LAM	NEO
	(39.30)	(49.60)	(41.00)	(34.20)	(36.80)
Post-test	PROG	PROG	NEO	NEO	NEO
	(35.50)	(51.20)	(38.80)	(34.70)	(49.60)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

When examine the use of models between pretest and posttest of individual students (Table 6.30), the results confirm the finding derived from Figured 3A. In all contexts, it found that the majority of students used non-scientific models over pretest and posttest (Non-sci to Non-sci category); 57.60 percent in bentgrass, 66.34 percent in moth, 49 percent in guppy, 49.03 percent in *E. coli* ,and 30 percent in Finch. In guppy, the Non-Sci to Sci category is found in significant percentage (34 percent). In

E .coli and finch, Neo-Darwinism is the most common model in both pretest and posttest. It also found that in these two contexts, the percentages of Sci-Sci and Non-Sci category is noticeable, although Non-Sci to Non-Sci is the most common category. In finch, for example, the percentages of Sci to Sci category are 25 while that of Non-Sci to Sci is 23.

Table 6.30 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Change in a Trait

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(5)	(5.43)	(5)	(4.95)	(7)	(7)	(13)	(13.83)	(25)	(25)
(1→ 1)	5	5.43	5	4.95	7	7	13	13.83	25	25
Scientific to Non –Scientific	(18)	(19.57)	(12)	(11.88)	(10)	(10)	(14)	(14.89)	(22)	(22)
(1→ 2)	0	0.00	0	0.00	4	4	8	8.51	2	2
(1→ 3)	14	15.22	7	6.93	4	4	5	5.32	16	16
(1→ 4)	4	4.35	5	4.95	2	2	1	1.06	4	4
Non - Scientific to Non - Scientific	(53)	(57.6)	(67)	(66.34)	(49)	(49)	(46)	(49.03)	(30)	(30)
(2→ 2)	2	2.17	1	0.99	3	3	1	1.07	3	3
(2→ 3)	1	1.09	6	5.95	8	8	1	1.07	5	5
(2→ 4)	3	3.26	0	0.00	2	2	3	3.19	3	3
(3→ 2)	0	0.00	4	3.96	4	4	2	2.15	1	1
(3→ 3)	16	17.39	29	28.71	17	17	5	5.33	12	12
(3→ 4)	12	13.04	7	6.93	4	4	10	10.65	2	2
(4→ 2)	1	1.09	4	3.96	5	5	4	4.27	2	2
(4→ 3)	6	6.52	11	10.89	4	4	10	10.65	1	1
(4→ 4)	12	13.04	5	4.95	2	2	10	10.65	1	1
Non – Scientific to Scientific	(16)	(17.4)	(17)	(16.83)	(34)	(34)	(21)	(22.25)	(23)	(23)
(2→ 1)	0	0.00	2	1.98	10	10	3	3.19	4	4
(3→ 1)	2	2.17	12	11.88	14	14	10	10.64	14	14
(4→ 1)	14	15.23	3	2.97	10	10	8	8.51	5	5
TOTAL	92	100	101	100	100	100	94	100	100	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Creationism (Gradualism) 4 = Lamarckism

Role of environment

Neo-Darwinism is the most common model in bentgrass, moth, and finch over pretest and posttest (Table 6.31). There is an increase in the use of the scientific model between pretest and posttest in all of these contexts; 46.20 to 49.60 percent in bentgrass, 36.80 to 47.90 percent in moth, 17.10 to 38 percent in guppy, 12.80 to 17.40 percent in *E. coli* and 40.20 to 43.80 percent in finch. The percentages of students using non-scientific model in these contexts drop noticeably. In guppy, there is a shift of the most common model between pretest and posttest from Lamarckism to Neo-Darwinism. *E. coli* is the only context that students preferred non-scientific model, Lamarckism by about 40 percent in both pretest and posttest.

Table 6.31 The Most Common Model for Each Context Role of Environment (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO (46.20)	NEO (36.80)	LAM (41.00)	LAM (43.60)	NEO (40.20)
Post-test	NEO (49.60)	NEO (47.90)	NEO (38.00)	LAM (43.80)	NEO (43.80)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

When examine the use of model of individual students (Table 6.32), it found that the percentage of student using scientific model in posttest partially were those changing non-scientific models to the scientific model after the instruction. Although the Non-Sci to Sci category is not the most common category in all contexts, the percentages of this category in these contexts were remarkable; 21.16 percent in bentgrass, 25.48 percent in moth, 29.36 percent in guppy, 18 percent in *E. coli* and 21.12 percent in finch. In bentgrass, moth, and finch, the percentages of Sci to Sci category are also notable; 28.85, 23.58 and 20 percent respectively.

Table 6.32 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Environment

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(30)	(28.85)	(25)	(23.58)	(12)	(11.01)	(4)	(4)	(18)	(20)
(1→ 1)	30	28.85	25	23.58	12	11.01	4	4	18	20
Scientific to Non –Scientific	(20)	(19.23)	(14)	(13.21)	(8)	(7.34)	(12)	(12)	(20)	(22.23)
(1→ 2)	7	6.73	2	1.89	0	0.00	2	2	6	6.67
(1→ 3)	7	6.73	10	9.43	4	3.67	9	9	9	10
(1→ 4)	6	5.77	2	1.89	4	3.67	1	1	5	5.56
Non - Scientific to Non - Scientific	(32)	(30.76)	(40)	(37.73)	(57)	(52.29)	(66)	(66)	(33)	(36.65)
(2→ 2)	2	1.92	1	0.94	5	4.59	9	9	2	2.22
(2→ 3)	5	4.81	10	9.43	5	4.59	8	8	0	0.00
(2→ 4)	5	4.81	2	1.89	6	5.50	3	3	1	1.11
(3→ 2)	3	2.88	1	0.94	8	7.34	9	9	3	3.33
(3→ 3)	8	7.69	19	17.92	11	10.09	22	22	10	11.11
(3→ 4)	2	1.92	0	0.00	7	6.42	5	5	4	4.44
(4→ 2)	1	0.96	2	1.89	4	3.67	1	1	4	4.44
(4→ 3)	4	3.85	3	2.83	9	8.26	6	6	4	4.44
(4→ 4)	2	1.92	2	1.89	2	1.83	3	3	5	5.56
Non – Scientific to Scientific	(22)	(21.16)	(27)	(25.48)	(32)	(29.36)	(18)	(18)	(19)	(21.12)
(2→ 1)	8	7.69	7	6.61	4	3.67	11	11	5	5.56
(3→ 1)	9	8.66	15	14.15	20	18.35	3	3	6	6.67
(4→ 1)	5	4.81	5	4.72	8	7.34	4	4	8	8.89
TOTAL	104	100	106	100	109	100	100	100	90	100

1 = Neo-Darwinism 2 = Dominant/Recessive Genes 3 = Lamarckism 4 = Creationism (Young Earth)

Speciation

The students still had difficulty in understanding the concept of speciation (Table 6.33). The majority of students used the same non-scientific models over pretest and posttest in all contexts except moth; Lamarckism in bentgrass, *E. coli* and finch, and Mutation in guppy. Moth is only context that the students used Neo-Darwinism the most in both pretest and posttest by 35 and 41.30 percent respectively. Interestingly, there is an increase in number of students using Lamarckism between pretest and posttest; 27.40 to 29.80 percent in bentgrass, 32.50 to 38.80 percent in *E. coli*, and 36.80 to 46.30 percent in finch. For this group of students, the instruction might not have corrected their prior knowledge but made it stronger. The instruction might also have made those already holding the scientific model unsure about their existing model and finally changed the scientific model to the non-scientific models.

Table 6.33 The Most Common Model for Each Context of Speciation (%)

Tests	Contexts				
	bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	NEO	MUT	LAM	LAM
	(27.40)	(35.00)	(35.00)	(32.50)	(36.80)
Post-test	LAM	NEO	MUT	LAM	LAM
	(29.80)	(41.30)	(33.90)	(38.80)	(46.30)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth), MU = Mutation

The examination of the use of models between pretest and posttest of individual students confirms this notion (Table 6.34). The Non Sci to Non Sci was found in the highest percentages compared to other categories in all contexts; 66.34 percent in bentgrass, 36.44 percent in moth, 53.46 percent in guppy, 58 percent in E. *coli* and 70.13 percent in finch. Among these non-scientific model holders consisted of the students who applied the same non-scientific model in both pretest and posttest the most. In finch, for example, among 70.13 percent of non-scientific model holders includes 27.84 percent of students who using Lamarckism over the two tests.

Classroom observation reveals what really happened in the classroom setting regarding this concept. By the end of implementation, Pinsuda could not finish the last two lessons in time; speciation, and Macroevolution. She had set up extra periods to sum up the two lessons. Under the time constraint, she had skipped all activities and exercises. She asked students to do the exercises by themselves in their own free time and did not give feedback on them. Therefore, the students did not know if what they understood was right or wrong.

Table 6.34 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Speciation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(4)	(3.96)	(15)	(15.63)	(9)	(8.91)	(10)	(10)	(7)	(7.22)
(1→ 1)	4	3.96	15	15.63	9	8.91	10	10	7	7.22
Scientific to Non –Scientific	(15)	(14.85)	(16)	(16.67)	(15)	(14.85)	(15)	(15)	(10)	(10.31)
(1→ 2)	5	4.95	5	5.21	3	2.97	1	1	4	4.12
(1→ 3)	3	2.97	7	7.29	4	3.96	8	8	6	6.19
(1→ 4)	7	6.93	4	4.17	8	7.92	6	6	0	0.00
Non - Scientific to Non - Scientific	(67)	(66.34)	(35)	(36.44)	(54)	(53.46)	(58)	(58)	(68)	(70.13)
(2→ 2)	9	8.91	7	7.29	5	4.95	3	3	6	6.18
(2→ 3)	11	10.89	9	9.38	3	2.97	7	7	10	10.30
(2→ 4)	6	5.94	1	1.04	5	4.95	7	7	0	0.00
(3→ 2)	6	5.94	3	3.13	3	2.97	3	3	7	7.22
(3→ 3)	10	9.90	4	4.16	5	4.95	17	17	27	27.84
(3→ 4)	5	4.95	1	1.04	8	7.92	11	11	3	3.09
(4→ 2)	2	1.99	4	4.16	5	4.95	1	1	7	7.22
(4→ 3)	6	5.94	2	2.08	9	8.91	5	5	8	8.28
(4→ 4)	12	11.88	4	4.16	11	10.89	4	4	0	0.00
Non – Scientific to Scientific	(15)	(14.85)	(30)	(31.26)	(23)	(22.78)	(17)	(17)	(12)	(12.34)
(2→ 1)	3	2.97	9	9.38	4	3.96	5	5	2	2.07
(3→ 1)	7	6.93	10	10.42	5	4.96	8	8	4	4.11
(4→ 1)	5	4.95	11	11.46	14	13.86	4	4	6	6.18
TOTAL	101	100	96	100	101	100	100	100	97	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Lamarckism 4 = Mutation

Finding II: To explain evolutionary process, the students did not hold a single model in their mind. They instead hold many and apply the one that most reasonable, to them, for a particular context and concept and this is consistent in both pretest and posttest.

Like the previous cases, Pinsuda's students inconsistently used models to explain evolutionary concepts. The pick of models was affected by context and concept the students were dealing. To investigate the effect of context on the choice of model, the percentage of a particular model across different contexts is examined (Table 6.35 by columns). It found that there is a fluctuation in the percentage of a particular model in the five contexts and no models is commonly used across the contexts. The percentage of Lamarckism in posttest of change in a trait, for example, varies across different contexts; 34.70 percent in bentgrass, 14.90 percent in moth, 10.70 percent in guppy, 32.20 percent in *E. coli*, and 9.90 percent in finch. Another example is the percentage of Progressive Creationism in posttest of origin of variation; 47.90 percent in bentgrass, 51.20 percent in moth, 29.80 percent in guppy, 46.30 percent in *E. coli* and 27.30 percent in finch. By these percentages, Progressive Creationism is the most common model in bentgrass, moth, and *E .coli* but not in guppy and finch. To investigate the effect of concept on the choice of model, the percentages of a particular model across different concepts of evolution is examined (Table 6.35 by rows). It found that in a context, there is fluctuation in the percentage of a particular model across varying concepts and the most common models of these concepts are not the same. A number of students preferred Progressive Creationism to explain origin of variation but Neo-Darwinism to explain role of variation and role of environment.

Table 6.35 The Percentages of Pinsuda's Students Using a Particular Model between Pretest and Posttest to Explain Various Concepts of Evolution across Five Contexts of Questions

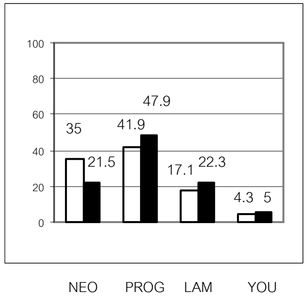
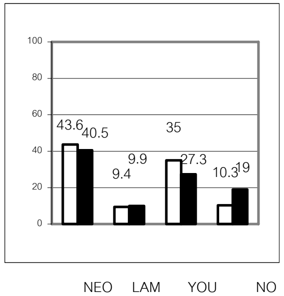
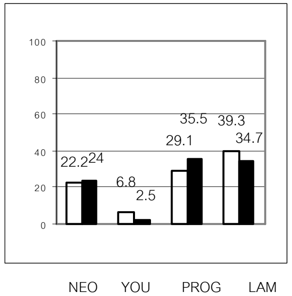
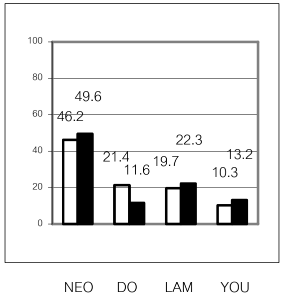
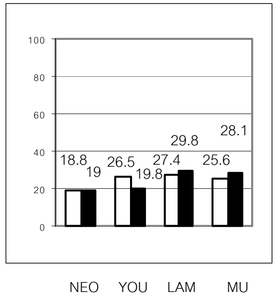
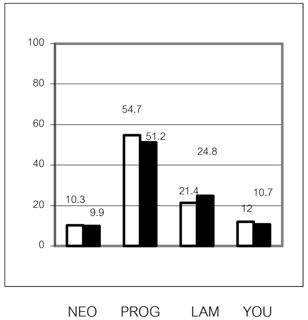
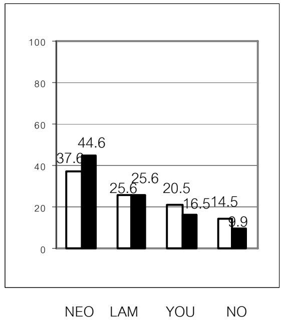
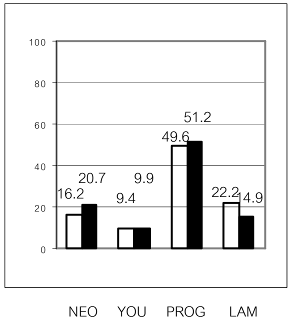
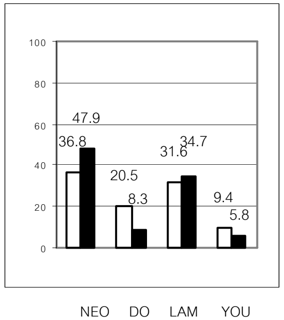
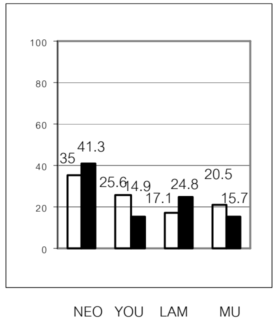
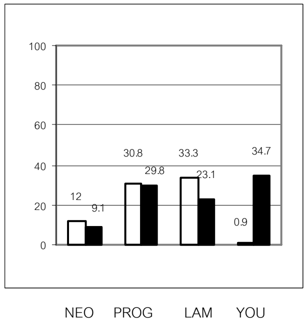
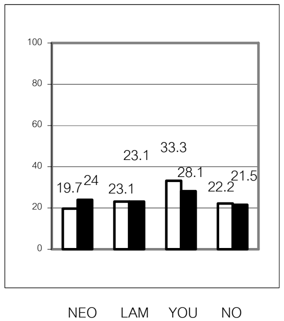
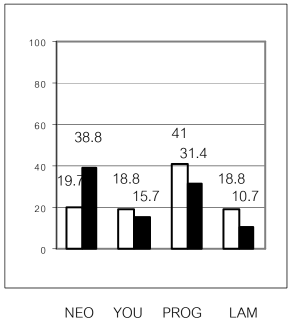
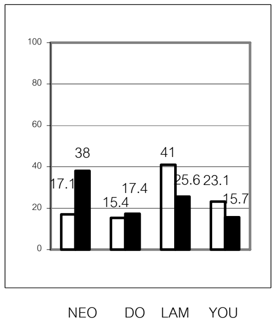
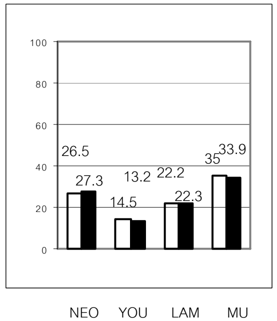
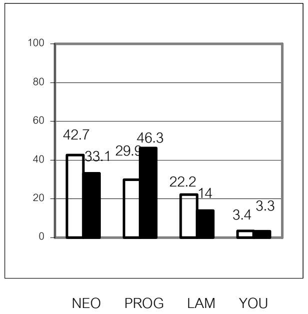
Concepts / Contexts	origin of variation	role of variation	change in a trait	role of environment	speciation
Bentgrass					
Moth					
Guppy					

Table 6.35 (Cont'd)

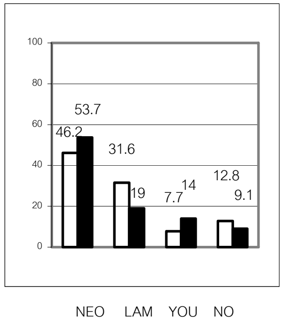
Concepts / Contexts: origin of variation | role of variation | change in a trait | role of environment | speciation

E.coli

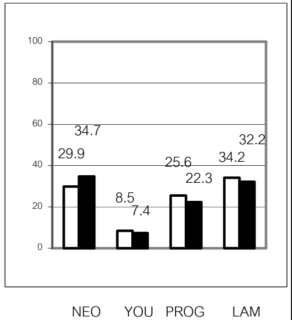
origin of variation



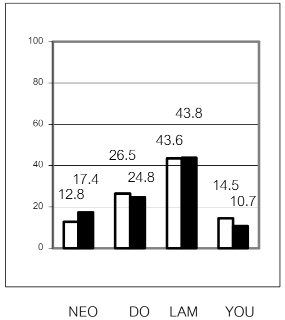
role of variation



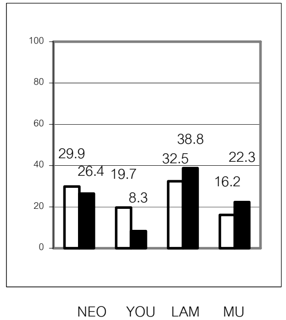
change in a trait



role of environment

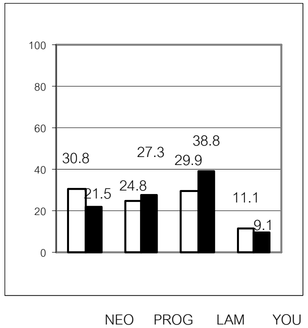


speciation

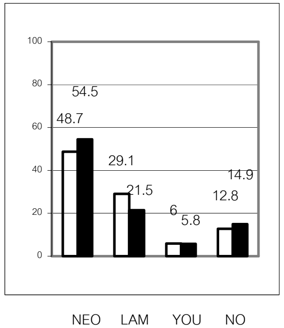


Finch

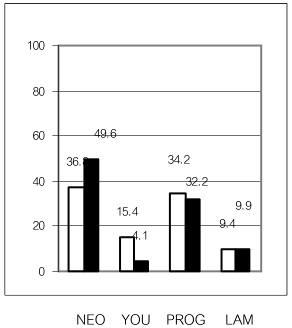
origin of variation



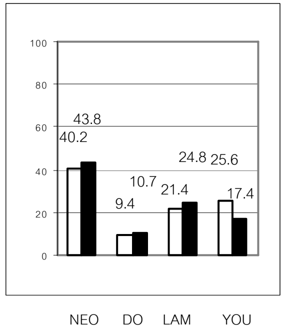
role of variation



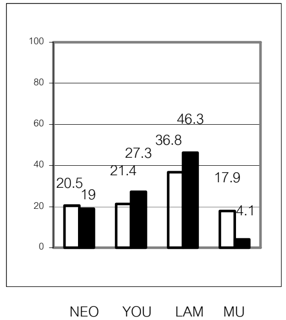
change in a trait



role of environment



speciation



□ = Pretest ∎ = Posttest

NEO = Neo-Darwinism LAM = Lamarckism PROG = Progressive Creationism YOU = Creationism (Young Earth) MU = Mutation NO = Variation has no effect

In-depth interviews were conducted immediately after the pretest with five students to examine their reasons behind the model preference over different contexts. The students were asked to give the reason they preferred to use a particular model over others in a particular context of question. From the test results, it was found that to explain the concept of speciation, many students preferred Progressive Creationism in moth but Lamarckism in *E. coli* and bentgrass. Interestingly, like students of Karnika and Sarapee, the students said that Progressive Creationism sound the most possible and sensible to them in moth and Lamarckism in *E. coli*. "Like us, the plant (bentgrass) responds to the changing environment (copper contamination) by gradually accumulating the tolerant capacity. Eventually, it will become new species". The student prefers to use Lamarckism to explain microscopic physiological characters but Creationism (gradualism) for macroscopic morphological characters.

The students were asked why they prefer a particular model to explain a particular concept of evolution; Progressive Creationism for origin of variation and Neo-Darwinism for role of variation and role of environment. Many students said that they really did not know where the variation within a population came from. It was logical for them to explain that the original trait must be part of the initial population. The new trait evolved from the existing trait by accident. "I really don't know how the white wings first occurred in the population. I think it might be already with the population since the moths were created by nature. The black wing moths evolved afterwards, of course, from the original type", one student said. This student said further that he had never been taught about the origin of variation before. He said he had learnt gene recombination and mutation in Genetics Unit but he did not know these two mechanisms were responsible for origin of variation. "She (Pinsuda) taught what mutation was, the effect of mutation, kinds of mutation; point and chromosome and that was all", he said. This student's answer was consistent with that of other students. Pinsuda taught mutation and genetic recombination but did not discuss its role in evolutionary change. In this case, she did not link the genetic concept with the evolutionary concept. In short, the instruction has effect on the students' use of model. It is the most important factor that determines the use of model of students.

In conclusion, the majority of students used scientific model to explain role of variation and role of environment. However, they still preferred non-scientific models to explain origin of variation, change in a trait and speciation. Classroom observation indicated that the use of these non-scientific models might be rooted in the instruction regarding these concepts. Pinsuda was not aware of students' non-scientific model. In a discussion of the adaptation of frog skin color, for example, although she used all questions as suggested in the lesson plan, she did not react to students' response not giving them feedback if their answers were right or wrong. She often ignored students' questions and dealing with conceptual conflict among students.

Pinsuda did not have strong genetic content knowledge. She did not refer nor explain the origin of variation in the process of natural selection. In the discussion on allele, gene, genotype and phenotype, she herself held a lot of misconceptions and passed them on to the students unintentionally. Content knowledge was her big problem in running ELU activities because she was still not clear about the concepts. She could not run some activities of ELU such as Counting Button lab exercise and working out genotypic and allele frequency of a given population. For the Counting Buttons, she asked the researcher to brief the lab the direction for students. As for working out genotypic and allele frequencies, she could not explain the procedure of solving problems to the students. She copied it form the teacher manual, paste it on the broad and asked students to take note. Any topics or activities that she was not confident in, she always skipped or gave the right answer from the manual right off to students. This might be the reason for student conceptual difficulties in understanding many topics of evolutionary process even after the instruction.

Case Study Four: Nanfah School (2)

This case is about Soyfah, the other biology teacher of Nanfah School who implemented the ELU. Because the implementation took place on the same site as that of Case Study Three: Nanfah School (1), the description on school context and classroom setting will not be included in this case.

Teacher and Student Background

Soyfah was 52 year old female teacher. She earned her B.Sc. in biology. In 1978, Soyfah started her teaching career as a biology teacher in a secondary school in Nakorn Pratom, a province about 56 kilometers from Bangkok. She had taught Grade 12 Biology (genetics and evolution) since then. Soyfah had attended many workshops. She wanted to update her content knowledge and learn new teaching strategies. After she had worked for a while, she had decided to come back to university to pursue her master degree in Environmental Science. In 1998, she moved to Nanfah School and had taught Grade 12 Biology. In 2002, Soyfah was also assigned to teach biology for Grade 10 students in the Gifted Program (Science), a study program designed for outstanding students in area of science and technology. In 2003, the time that the ELU was implemented, she stepped out of Grade 12 biology. She taught biology only for students in the gifted program and, in the same year, she was appointed to be the head of the office of registrar. She took responsibility for providing academic services to students; organizing class and exam schedules, registration, issuing grade report, transcript, and registration information sheet.

In 2003, however, at the request of Pinsuda, Soyfah decided to keep one class of Grade 12, so Pinsuda could observe her teaching and consulted her when she had any problems. That was a high ability class, the top class of Science and Mathematic Study Program. There were 42 students; 10 boys and 32 girls. Eighty one percent of them were 17-18 years old. Eighty eight percent of students had GPA higher than 3.00 in a four-point grading system. No students in this class had failed biology in the previous semester. Eighty six percent of them got grade 3 (Above Average) and grade 4 (Excellent). Sixty percent of students had decided not to use biology for the entrance examination. The first round entrance examination results that more than 50 percent of students had already met the admission requirements of the program they were applying for.

Soyfah is the only teacher in this study who, before the implementation of the ELU, had not followed IPST textbook. From her point of view, IPST textbook did not provide an opportunity to her students to actively involve in learning process. The textbook was, therefore, used as an optional learning resource. She had developed her own teaching materials and activities. On the topic Models of Evolution, for example, she asked students to engage in debate on "Lamarckism VS Darwinism". She said that the students liked this activity every much. When asked to implement the ELU, Soyfah expressed her appreciation and willingly and was keen to participate in the implementation. She found this study was relevant to what she had been doing.

Research question III: How do the teachers implement ELU in their own context?

This section centers on the implementation of the ELU in one class of Grade 12 students of Nanfah School by Soyfah. The section describes this teacher's teaching practice; teaching strategy, use of instructional media and material, and assessment techniques. The classroom interaction was investigated and discussed. In the end of this section, the effect of the implementation on teacher's future teaching practice is discussed.

Teaching practice

Soyfah followed the teacher manual of the ELU. She taught evolution in the sequence as suggested by the manual, not skipping any topics and activities and making use of all instructional materials and media. She tried to get to know student understanding before introducing a lesson. When she found the students held a non-scientific model, she challenged the idea by asking another situation for which it could not be applied. She reviewed the fundamental concepts if they were needed. She did not convey to them the scientific concept but encouraged them to figure it out for themselves.

Soyfah used her initiative to make the instructions more effective. For example, before starting any lessons, she wrote the objectives of the lesson on the transparency and discussed what the students were expected to be able to do and understand after studying. This is a way to make the student clear right from the beginning about what they need to focus on. During the instruction, she showed the students the transparency to remind them which objectives that they were trying to achieve. "I always do that. It is a pretty good idea to have a clear whole picture at the beginning. Many of our students do the activity without knowing why they have to do so. Nor could they make a conclusion from such activity. It's kind of when hands are on, mind goes off. This would help them back on track", Soyfah said. Soyfah had used this technique for years. This means that she had combined her own teaching technique with the teaching strategies of the ELU to improve the effectiveness of the intervention.

Soyfah made a link between the topics of evolution. In the Lesson Two, Models of Evolution, she told it was necessary for the students to have sound understanding of the three models of evolution, especially the scientific model, Neo-Darwinism since they would refer to it in the following lessons, Population at the Equilibrium and Evolving Population.

She used a variety of assessment techniques in her instruction. To evaluate student learning, she took into account test performance, classroom participation in discussion sessions and activities, report and classroom presentation. She said that her assessment not primarily aimed to evaluate student learning but also to assist their learning and improve teaching. She spent time in reading student worksheets and journal. She considered student response carefully trying to identify the students' conceptual difficulties and adjusted her instruction to help students understand the concepts. She gave feedback to the students immediately so the students were aware of any gaps that exist between the expected learning outcome and their existing understanding.

Classroom interaction

Soyfah encouraged the interaction between teacher and students and between students and students. The interaction was not predominated by the teacher nor a few students. She encouraged all students to participate in the discussion. Soyfah did not deliver knowledge to students but used dialectic to help students construct the knowledge by themselves. She always asked a series of questions to students until they developed sound understanding of the concept. The questions she asked include those planned in the manual and those made by her promptly to deal with the unexpected response. Each student was asked to give the logical argument and evidence. They were also asked to consider the ideas that were opposed to their ideas. To support these arguments, the discussion between Soyfah and her students about the difference between Creationism, Lamarckism and Darwinism of Lesson Two, Model of Evolution as follows is examined. This discussion was made after the students had listened to the excerpts of the original writings of Paley, Lamarck and Darwin.

Soyfah:	…So you think that Creationists thought everything was created by god and it has been fixed since then, hasn't it?
Ss	Yes
Soyfah	OK. Have a look at this (point at Lamarckism's excerpt in student manual). Did Lamarck believe in change of living thing over time?
Ss:	Yes.
Soyfah:	Are there any differences between Lamarck's and Paley's?
S1:	Lamarck thought that living things changed but Paley didn't.
Soyfah:	How do the rest of you think about it? Agree with S1?
Ss:	Yes.
Soyfah:	Yes, S1 was right. We know that Lamarck believed that

	organisms did change over time. To his view, what made the organisms change?
Ss:	Environment
Soyfah:	How?
S3:	Environment causes the organism to overuse or disuse a particular organ. Later, that part will become larger or deteriorate bit by bit.
Soyfah:	Suppose that you lifted a dumbbell only by your left hand everyday, will both of your shoulders get the same size?
Ss:	No
Soyfah:	Why?
Ss:	Left hand is used more often so its muscles grow bigger.
Soyfah:	Do you think Darwin's idea is similar to or different from Paley's and Lamarck's idea?
S2:	Different from Paley's but quite similar to Lamarck's
Soyfah:	Why do you think it is quite similar to Lamarck's?
S2:	Darwin also thought that the organisms change over time.
Soyfah:	Do Lamarck and Darwin explain the mechanism of the change in the same way?
Ss:	No
S3:	As for Darwin, natural selection
Soyfah:	How does nature select? I mean how nature determines… this will be selected in and that will be eliminated?
Ss:	(discussed with each other)
Soyfah:	Guys…listen (call for attention). Suppose that in this room, there was one student catching a cold. He coughed and sneezed all the time. Two days later some of you caught a cold while many of you didn't even you all had been in the classroom as the sick student in that day. How would you explain this?
Ss:	(discussed with each other)

Soyfah: Why someone got sick while many didn't? What make someone more preferable in that situation?

S6: Their good immune system?

Soyfah: Yeah. Different people have different quality of immune system. In such environment, therefore, only those have strong, effective immune system are not infected by the disease.

From this dialogue, Soyfah did not tell the students the concept but she facilitated them to develop the understanding of the concept on their own. Above, she first asked students to carefully listen and read the original writing of the three naturalists, identify the assumptions of each model and make a comparison between the three models. She used a series of questions to help students do so, such as "were Paley's and Lamarck's ideas different? If they were, how?"; " What did Darwin's and Lamarck's ideas share in common and differ?"; and "What did they explain the mechanism of evolution?" When she found student explanation was still ambiguous, she gave some more examples. For instance, when one student (S3) said Darwin explained evolutionary change by natural selection; she asked how nature selected the character. When she noticed that this student and most of other students were uncertain about this, she gave the example of the individual difference in immunological system to help them understanding the mechanism of natural selection.

<u>Teacher's conceptual difficulties and awareness of students' non scientific ideas</u>

From classroom observation, Soyfah did not have problems about the content of evolution and the ELU activities. She had strong content knowledge. She understood and could run the activities. Unlike the teachers of the other cases, Soyfah was the only teacher in this study who, in the discussion of the adaptation of frog skin color discussed the concept origin of variation. She talked about the sources of genetic variation including gene recombination and mutation. She explained that the genetic variation was the input of natural selection process and addressed the connection between genetics and evolution. “Without a full understanding of genetics, the students could not explain evolutionary process” Soyfah said in the discussion. This shows that the teacher must have had strong content background in both topics.

The effect of the implementation of the ELU on teachers’ teaching practice

Soyfah herself had changed her teaching style before the implementation of ELU. From many years of teaching experience, she found that the biggest problem of teaching evolution was that the students from all ranges of learning ability, paid low attention to the topic. The students would like to allocate the time for evolution to university entrance preparation. They had asked Soyfah to cancel the class so they could spend that amount of time reading and doing former entrance exams of other subjects such as math, physic and chemistry. Soyfah wanted the students to pay more attention to evolution. Over years, she had developed many activities to capture student interest and attention. Therefore, Soyfah found the implementation of the ELU was supportive to what she had been doing. The ELU suggested to her many more practical ideas on how to make the lesson lively and enjoyable. She said she felt it was fun to try out the new teaching methods and happy to see students enthusiastically and excitedly participating in ELU activities. Soyfah said that she would definitely used the ELU activities and materials during the following academic years.

In conclusion, Soyfah followed the guidelines of the ELU. She used all teaching materials to run the activities. In each lesson, she paid attention to the students prior knowledge. She allowed the students to fully engage in the activities to construct the knowledge for themselves. Soyfah always had discussions with the students. She invited all students to participate in the discussions. She stimulated student thinking by raising a series of question. She kept posing questions to the students all the time during the discussions until they developed scientific conceptions. She made the conversation flow logically based on the students' answers. Soyfah enjoyed teaching evolution by the ELU even though she was distracted by administrative work at some stages.

Research Question IV: Does the Evolution Learning Unit (ELU) enhance student understanding of Evolution?

Finding I: After the instruction, there is an increase in the number of students using Neo-Darwinism in the concepts of role of variation, role of environment, and speciation. The students had difficulty in understanding origin of variation and change in a trait. The students' prior model of origin of variation is resistant to change.

Origin of variation

The students did not use Neo-Darwinism the most to explain the concept of origin of variation in all contexts (Table 6.36). This is found in pretest and posttest. Progressive Creationism was used the most in pretest and posttest in the contexts of bentgrass, moth and *E. coli* by more than 50 percent of students. In guppy, the students used Neo-Darwinism, Progressive Creationism and Creationism (young earth) by the same percentage in pretest, 28.60 percent and used Progressive Creationism the most in posttest by 31 percent. However, the percentages of other models in posttest are not different. In this context, the students must have had a variety of ideas about the cause of variation. In finch, the majority of students preferred Lamarckism in both pretest and posttest by 66.70 and 64.30 percent respectively.

Table 6.36 The Most Common Model for Each Context of Origin of Variation (%)

	Contexts				
Test	Bentgrass	Moth	Guppy	*E. coli*	Finch
Pre-test	GRAD (54.80)	GRAD (71.40)	NEO,GRAD, YOU (28.60)	GRAD (59.50)	LAM (66.70)
Post-test	GRAD (61.90)	GRAD (59.50)	GRAD (31.00)	GRAD (61.90)	LAM (64.30)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

The use of non-scientific models between pretest and posttest over different contexts is confirmed when examined the use of model of individual students in pretest and posttest (Table 6.37). It found that the most common category of all contexts is Non- sci to Non-sci category; 56.10 percent in bentgrass, 68.29 percent in moth, 60 percent in guppy, 56.41 percent in E. coli and 80.49 percent in finch. Among these are the students who consistently applied the same non-scientific models over pretest and posttest. In E. coli, for example, 30.77 out of 56.41 percent of Non-Sci to Non-Sci category is those holding Progressive Creationism over the two tests. This shows the resistance of student prior knowledge even in these students that had been taught the correct concept by Soyfah. As for other categories, their percentages are not high. The change of models from non-scientific to scientific is found by a significant percentage in moth, 21.95 percent.

Table 6.37 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Origin of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(7)	(17.07)	(0)	(0.00)	(2)	(5)	(3)	(7.69)	(4)	(9.76)
(1→ 1)	7	17.07	0	0.00	2	5	3	7.69	4	9.76
Scientific to Non –Scientific	(6)	(14.63)	(4)	(9.76)	(9)	(22.5)	(9)	(23.07)	(1)	(2.44)
(1→ 2)	6	14.63	1	2.44	4	10	8	20.51	1	2.44
(1→ 3)	0	0.00	2	4.88	1	2.5	1	2.56	0	0.00
(1→ 4)	0	0.00	1	2.44	4	10	0	0.00	0	0.00
Non - Scientific to Non - Scientific	(23)	(56.10)	(28)	(68.29)	(24)	(60)	(21)	(56.41)	(33)	(80.49)
(2→ 2)	11	26.83	17	41.46	5	12.5	12	30.77	2	4.88
(2→ 3)	4	9.76	4	9.76	2	5	4	10.26	4	9.76
(2→ 4)	0	0.00	2	4.88	3	7.5	1	2.56	1	2.44
(3→ 2)	4	9.76	1	2.44	2	5	4	10.26	2	9.76
(3→ 3)	1	2.44	3	7.32	3	7.5	0	0.00	18	43.90
(3→ 4)	0	0.00	0	0.00	1	2.5	1	2.56	1	2.44
(4→ 2)	3	7.32	1	2.44	2	5	0	0.00	5	12.20
(4→ 3)	0	0.00	0	0.00	3	7.5	0	0.00	0	0.00
(4→ 4)	0	0.00	0	0.00	3	7.5	0	0.00	0	0.00
Non – Scientific to Scientific	(5)	(12.20)	(9)	(21.95)	(5)	(12.5)	(6)	(13.38)	(3)	(7.32)
(2→ 1)	5	12.20	4	9.76	2	5	6	13.38	1	2.44
(3→ 1)	0	0.00	0	0.00	1	2.5	0	0.00	1	2.44
(4→ 1)	0	0.00	5	12.20	2	5	0	0.00	1	2.44
TOTAL	41	100	41	100	40	100	39	100	41	100

1 = Neo-Darwinism 2 = Creationism (Gradualism) 3 = Lamarckism 4 = Creationism (Young Earth)

Role of variation

Neo-Darwinism is the most common model used by the students to explain the concept of role of variation in all contexts in pretest and posttest (Table 6.38). The increase in number of students using the scientific model was found in all contexts except *E. coli* whose percentage of the scientific model holders in pretest and posttest is the same, by 73.80 percent. The percentage of students using the scientific model in other contexts increases dramatically ranging form 14 to 35 percent.

Table 6.38 The Most Common Model for Each Context of Role of Variation (%)

	Contexts				
Tests	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	NEO	NEO	NEO	NEO
	(40.50)	(42.90)	(40.50)	(73.80)	(66.70)
Post-test	NEO	NEO	NEO	NEO	NEO
	(71.40)	(78.60)	(59.50)	(73.80)	(81.00)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

The examination the use of model of individual students between pretest and posttest explains where these high percentages of scientific model holders come from (Table 6.39). The most common categories of use of model between pretest and posttest are Sci to Sci category in *E. coli* and finch and Non-sci to Sci category in the other contexts. This means that there must have had some students consistently using their scientific model over pretest and posttest and some who decided to change their model from non-scientific to scientific model after the instruction. To the former, the instruction must have confirmed what they had previously known. The scientific mode was supported and strengthened throughout the period of instruction. For the latter, the instruction might have shown the students the weaknesses of their non-scientific models and strengths of the scientific model that had more explanatory power. The percentages of other categories, Non-Sci to Non-Sci and Sci to Non-Sci were also found but much less.

Table 6.39 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Variation

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(11)	(27.5)	(14)	(35)	(10)	(25)	(24)	(57.14)	(22)	(53.66)
(1→ 1)	11	27.5	14	35	10	25	24	57.14	22	53.66
Scientific to Non –Scientific	(3)	(7.5)	(3)	(7.5)	(5)	(12.5)	(5)	(11.9)	(3)	(7.32)
(1→ 2)	1	2.5	2	5	1	2.5	4	9.52	1	2.44
(1→ 3)	2	5	1	2.5	3	7.5	1	2.38	1	2.44
(1→ 4)	0	0.00	0	0.00	1	2.5	0	0.00	1	2.44
Non - Scientific to Non - Scientific	(8)	(20)	(6)	(15)	(10)	(25)	(5)	(11.9)	(5)	(12.2)
(2→ 2)	1	2.5	0	0.00	2	5	1	2.38	1	2.44
(2→ 3)	2	5	2	5	2	5	2	4.76	0	0.00
(2→ 4)	0	0.00	1	2.5	0	0.00	0	0.00	2	4.88
(3→ 2)	1	2.5	0	0.00	0	0.00	1	2.38	0	0.00
(3→ 3)	1	2.5	3	7.5	3	7.5	0	0.00	1	2.44
(3→ 4)	0	0.00	0	0.00	1	2.5	1	2.38	0	0.00
(4→ 2)	1	2.5	0	0.00	1	2.5	0	0.00	0	0.00
(4→ 3)	1	2.5	0	0.00	1	2.5	0	0.00	0	0.00
(4→ 4)	1	2.5	0	0.00	0	0.00	0	0.00	1	2.44
Non – Scientific to Scientific	(18)	(45)	(17)	(42.5)	(15)	(37.5)	(8)	(19.06)	(11)	(26.82)
(2→ 1)	3	7.5	7	17.5	5	12.5	3	7.15	5	12.19
(3→ 1)	12	30	6	15	2	5	5	11.91	1	2.44
(4→ 1)	3	7.5	4	10	8	20	0	0.00	5	12.19
TOTAL	40	100	40	100	40	100	42	100	41	100

1 = Neo-Darwinism 2 = Lamarckism 3 = Creationism (Young Earth) 4 = No Effect…Same Species

Change in a trait

The most common models for change in a trait are varied across different contexts in pretest and posttest (Table 6.40). Neo-Darwinism was used the most in guppy and finch in pretest and posttest by more than 40 percent of students. In bentgrass, the majority of students preferred Lamarckism in pretest and posttest by 40.50 and 47.60 percent respectively. Lamarckism was also chosen the most in *E. coli*, 47.60 percent in pretest but Neo-Darwinism was preferred by 41 percent in posttest. In moth, the majority of students preferred non-scientific model over pretest and posttest; Creationism (young earth) in pretest by 73.80 percent and Progressive Creationism in posttest by 61.90 percent.

Table 6.40 The Most Common Model for Each Context of Change in a Trait (%)

	Contexts				
Test	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	YOU	NEO	LAM	NEO
	(40.50)	(73.80)	(40.50)	(47.60)	(54.80)
Post-test	LAM	GRAD	NEO	NEO	NEO
	(47.60)	(61.90)	(42.90)	(40.50)	(64.30)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

The high number of student using non-scientific model was examined by considering the use of model of individual students between pretest and posttest (Table 6.41). Correspondingly, the most common categories of the use of model between pretest and posttest are varied context by context. Non-sci to Non-sci category was found the most common in bentgrass and moth by 55 and 56.41 percent respectively. Sci to Non-sci and Non-sci to Non-sci categories are both the most common in guppy by the same percentage, 29.27 percent. Sci to Sci category is the most common in finch by 45 percent while Non-sci to Sci category is the most common use of model in *E. coli* by 33.33 percent. This shows that the student were unconfident in any model so they used many models interchangeably across different contexts. This can be explained when look back at their classroom experience.

Even though Soyfah discussed them the scientific model of this concept many times for example, in the discussion of the adaptation of frog skin color and the industrial melanism in peppered moth, she did not put an emphasis on natural selection as evolutionary process at a population level, not an individual level and it always took age over generations. The reduction in proportion is gradually occurred over generations and could be only detected in a long run. Soyfah, like the teachers of the other cases, only said that, for those without the favorable character to the existing environment would become less and less. Consequently, some students might have thought that those organisms would be wiped out within its life span. This understanding is consistent with Lamarckism; only adapted individuals could pass on the favored character to the offspring whereas those without such character would die and be eliminated from the population in one generation. The character itself changed. To help student get around this point, Counting Button activity is advisable. Unfortunately, there were teachers in this study could run the activity and have a discussion on the change in allele and genotypic frequencies from the experiment.

Table 6.41 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Change in a Trait

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(2)	(5)	(2)	(5.13)	(6)	(14.63)	(5)	(12.82)	(18)	(45)
(1→ 1)	2	5	2	5.13	6	14.63	5	12.82	18	45
Scientific to Non –Scientific	(5)	(12.5)	(5)	(12.82)	(12)	(29.27)	(9)	(23.08)	(5)	(12.5)
(1→ 2)	0	0.00	2	5.13	6	14.63	0	0.00	1	2.5
(1→ 3)	3	7.5	3	7.69	5	12.20	2	5.13	4	10
(1→ 4)	2	5	0	0.00	1	2.44	7	17.95	0	0.00
Non - Scientific to Non - Scientific	(22)	(55)	(22)	(56.41)	(12)	(29.27)	(12)	(30.77)	(9)	(22.5)
(2→ 2)	0	0.00	0	0.00	1	2.44	0	0.00	0	0.00
(2→ 3)	0	0.00	0	0.00	2	4.88	0	0.00	1	2.5
(2→ 4)	0	0.00	0	0.00	0	0.00	0	0.00	1	2.5
(3→ 2)	0	0.00	1	2.56	2	4.88	0	0.00	0	0.00
(3→ 3)	5	12.5	16	41.03	5	12.20	2	5.13	6	15
(3→ 4)	4	10.00	1	2.56	0	0.00	1	2.56	0	0.00
(4→ 2)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
(4→ 3)	2	5.00	4	10.26	2	4.88	4	10.26	1	2.5
(4→ 4)	11	27.5	0	0.00	0	0.00	5	12.82	0	0.00
Non – Scientific to Scientific	(11)	(27.5)	(10)	(25.64)	(11)	26.83	(13)	(33.33)	(8)	(20)
(2→ 1)	0	0.00	1	2.56	3	7.32	2	5.13	0	0.00
(3→ 1)	7	17.5	9	23.08	7	17.07	2	5.12	5	12.5
(4→ 1)	4	10.00	0	0.00	1	2.44	9	23.08	3	7.5
TOTAL	40	100	39	100	41	100	39	100	40	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Creationism (Gradualism) 4 = Lamarckism

Role of environment

Neo-Darwinism is the most common model for role of environment in all contexts in both pretest and posttest except *E. coli* (Table 6.42). In *E .coli*, the majority of students preferred Lamarckism to other models by 54.80 and 57.10 percent in pretest and posttest respectively. In the other contexts, the students used the scientific model by more than 50 percent. The increase in the use of Neo-Darwinism is also found in these contexts. In moth, in a particular, the percentage of scientific model holders increases from 47.60 to 81 percent.

Table 6.42 The Most Common Model for Each Context of Role of Environment (%)

Tests	Contexts				
	Bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	NEO	NEO	NEO	LAM	NEO
	(66.70)	(47.60)	(47.60)	(54.80)	(54.80)
Post-test	NEO	NEO	NEO	LAM	NEO
	(71.40)	(81.00)	(73.80)	(57.10)	(73.80)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth)

This is consistent with the findings of the examination of the use of models of individual students between pretest and posttest (Table 6.43). Sci to Sci and Non-Sci to Sci categories are the most common use of model between pretest and posttest in all contexts except *E. coli* where Non-Sci to Non-Sci is found the most by 65 percent of students. The increase in using the scientific model in the other contexts is similar to that of role of variation because these two concepts are closely related to each other theoretically. To these group of students, the instruction must have challenged the non-scientific models but supported and strengthen the scientific models.

Table 6.43 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Role of Environment

Use of Models (pre→ post)	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(18)	(45)	(16)	(47.06)	(15)	(37.5)	(6)	(15)	(16)	(40)
(1→ 1)	18	45	16	47.06	15	37.5	6	15	16	40
Scientific to Non –Scientific	(8)	(20)	(3)	(8.82)	(4)	(10)	(1)	(2.5)	(7)	(17.5)
(1→ 2)	1	2.5	0	0.00	0	0.00	0	0.00	1	2.5
(1→ 3)	3	7.5	2	5.88	3	7.5	1	2.5	4	10
(1→ 4)	4	10	1	2.94	1	2.5	0	0.00	2	5
Non - Scientific to Non - Scientific	(3)	(7.5)	(5)	(14.7)	(5)	(12.5)	(26)	(65)	(4)	(10)
(2→ 2)	0	0.00	0	0.00	1	2.5	1	2.5	1	2.5
(2→ 3)	0	0.00	1	2.94	0	0.00	6	15	0	0.00
(2→ 4)	1	2.5	0	0.00	1	2.5	1	2.5	0	0.00
(3→ 2)	1	2.5	0	0.00	0	0.00	4	10	0	0.00
(3→ 3)	0	0.00	3	8.82	3	7.5	11	27.5	2	5
(3→ 4)	1	2.5	1	2.94	0	0.00	1	2.5	0	0.0
(4→ 2)	0	0.00	0	0.00	0	0.00	1	2.5	1	2.5
(4→ 3)	0	0.00	0	0.00	0	0.00	1	2.5	0	0.00
(4→ 4)	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Non – Scientific to Scientific	(11)	(27.5)	(10)	(29.42)	(16)	(40)	(7)	(17.5)	(13)	(32.5)
(2→ 1)	3	7.5	4	11.76	6	15	0	0.00	2	5
(3→ 1)	3	7.5	5	14.72	9	22.5	5	12.5	9	22.5
(4→ 1)	5	12.5	1	2.94	1	2.5	2	5	2	5
TOTAL	40	100	34	100	40	100	40	100	40	100

1 = Neo-Darwinism 2 = Dominant/Recessive Genes 3 = Lamarckism 4 = Creationism (Young Earth)

Speciation

The students preferred Neo-Darwinism the most in posttest in all concepts except finch (Table 6.44). In finch, the majority of students used Lamarckism to explain speciation by 69 and 59.50 in pretest and posttest respectively. There is a shift of most common model from non-scientific models to scientific model; Lamarckism to Neo-Darwinism in bentgrass and *E. coli* and Mutation to Neo-Darwinism in guppy. The percentages of non-scientific model in these contexts in posttest noticeably drop.

Table 6.44 The Most Common Model for Each Context of Speciation

	Contexts				
Tests	bentgrass	Moth	Guppy	*E.coli*	Finch
Pre-test	LAM	NEO	MUT	LAM	LAM
	(42.90)	(59.50)	(38.10)	(38.10)	(69.00)
Post-test	NEO	NEO	NEO	NEO	LAM
	(61.90)	(64.30)	(54.80)	(47.60)	(59.50)

NEO = Neo-Darwinism, LAM = Lamarckism, PROG = Progressive Creationism, YOU = Creationism (young earth) MU = Mutation

The examination of use of model of individual students between pretest and posttest explain the dramatic increase in the use of the scientific model after instruction (Table 6.45). In all most contexts, the most common categories are Non-sci to Sci and Sci to Sci. In bentgrass and *E. coli*, the Non-sci to sci category is found the most common by 48.76 and 37.50 percent respectively. Classroom experience might have enhanced these students understanding of this concept. In moth, Sci to Sci is the most common category by 37.50 percent. In guppy, Sci to Sci and Non-Sci to Sci are found the most common by the same percentage, 30 percent. Although Soyfah could not finish the last two lessons, speciation and Macroevolution on time, she made up extra period to summarize the key ideas of the two lessons. At that time, she had no time to run Classification and Evolution of Caminacules but she asked students to do all exercises in the worksheet and spent great amount of time discussing on the exercises to make sure that the student understood the process of speciation and macroevolution thoroughly. Finch is the only context that the majority of students used the non-scientific model over pretest and posttest. Non-Sci to Non-Sci category in this context is 64.10 percent.

Table 6.45 The Frequencies and Percentages of Individual Students Using Models in Pretest and Posttest to Explain the Concept of Speciation

	Contexts									
	Bentgrass		Moth		Guppy		*E. coli*		Finch	
Use of Models (pre→ post)	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Scientific to Scientific	(5)	(12.20)	(15)	(37.5)	(12)	(30)	(7)	(17.5)	(4)	(10.26)
(1→ 1)	5	12.20	15	37.5	12	30	7	17.5	4	10.26
Scientific to Non –Scientific	(2)	(4.88)	(8)	(20)	(2)	(5)	(4)	(10)	(1)	(2.56)
(1→ 2)	1	2.44	0	0.00	0	0.00	1	2.5	0	0.00
(1→ 3)	1	2.44	5	12.5	1	2.5	1	2.5	1	2.56
(1→ 4)	0	0.00	3	7.5	1	2.5	2	5	0	0.00
Non - Scientific to Non - Scientific	(14)	(34.16)	(8)	(20)	(14)	(35)	(14)	(35)	(25)	(64.1)
(2→ 2)	1	2.44	1	2.5	2	5	0	0.00	0	0.00
(2→ 3)	1	2.44	0	0.00	0	0.0	1	2.5	5	12.82
(2→ 4)	2	4.88	3	7.5	1	2.5	2	5	0	0.00
(3→ 2)	3	7.32	1	2.5	1	2.5	0	0.00	2	5.13
(3→ 3)	2	4.88	1	2.5	1	2.5	5	12.5	17	43.59
(3→ 4)	0	0.00	0	0.00	3	7.5	2	5	0	0.00
(4→ 2)	0	0.00	0	0.00	0	0.00	1	2.5	0	0.00
(4→ 3)	1	2.44	1	2.5	2	5	3	7.5	1	2.56
(4→ 4)	4	9.76	1	2.5	4	10	0	0.00	0	0.00
Non – Scientific to Scientific	(20)	(48.76)	(9)	(22.5)	(12)	(30)	(15)	(37.5)	(9)	(23.08)
(2→ 1)	3	7.32	4	10	1	2.5	4	10	1	2.57
(3→ 1)	11	26.83	3	7.5	1	2.5	5	12.5	7	17.95
(4→ 1)	6	14.61	2	5	10	25	6	15	1	2.56
TOTAL	41	100	40	100	40	100	40	100	39	100

1 = Neo-Darwinism 2 = Creationism (Young Earth) 3 = Lamarckism 4 = Mutation

Finding II: To explain evolutionary process, the students did not hold a single model in their mind. They instead hold many and apply the one that most reasonable, to them, for a particular context and concept and this is consistent in both pretest and posttest.

Like the other cases of this study, Soyfah's students have inconsistence in using a model of evolution. When asked to explain evolutionary concepts, the students chose the model that best fit and most reasonable, to them, for a particular context and concept. When examine the percentage of student using a particular model for a concept of evolution across different contexts (Table 6.46 by columns), it found that the percentage is varied. In posttest in the concept of change in a trait, for example, the percentages of Progressive Creationism are all different ranging from 21.40 percent in *E. coli* to 61.90 percent in moth. The latter percentage makes Progressive Creationism become the most common model in Moth. The in-depth interview of five students with a group of students who preferred this model to the other models reveals the logic behind their idea. Two students thought that it was more reasonable and relevant to them to explain the change of macroscopic and morphological character by Progressive Creationism; the new character evolves from original, God-created character. To them, Lamarckism was more appropriate to explain microscopic and physiological character as that of *E. coli*. In this context, the students explained that the organisms gradually accumulated antibiotic resistant capacity during its life span and passed the adapted character to the next generation. In Soyfah's case, interestingly, it also found that a number of students preferred Lamarckism, 69 percent in pretest and 59.50 percent in posttest, to explain speciation of the finches, even its character, beak type, is explicitly morphological. The students reasoned that the finch could physically use its beak. The finch, by themselves, could determine the change by overusing and disusing its beak on different kinds of food. This led to the differentiation among finches in various areas in Galapagos Archipelago and finally they would become different species. It is unlike the moth case whose change of the character (morphological), wing color, is very much determined by the environmental condition.

Table 6.46 The Percentages of Soyfah's Students Using a Particular Model between Pretest and Posttest to Explain Various Concepts of Evolution across Five Contexts of Questions

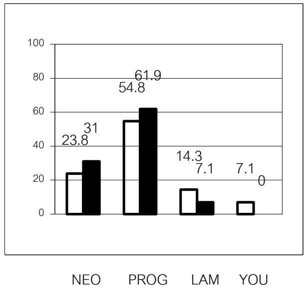
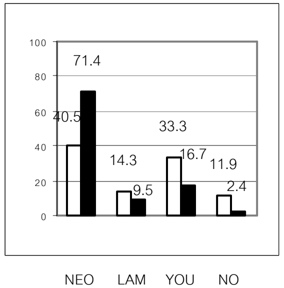
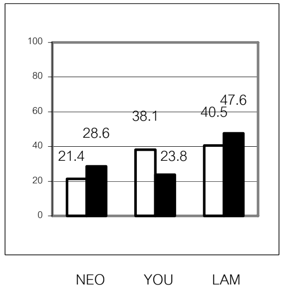
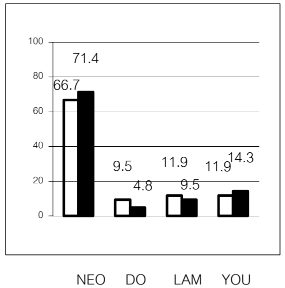
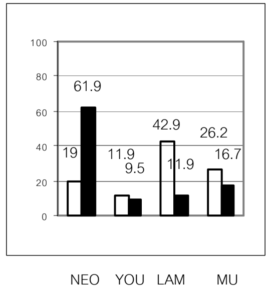
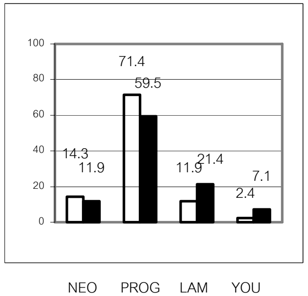
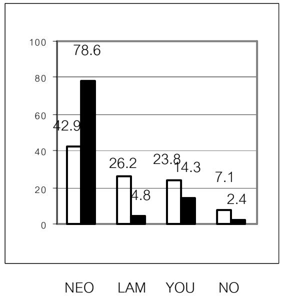
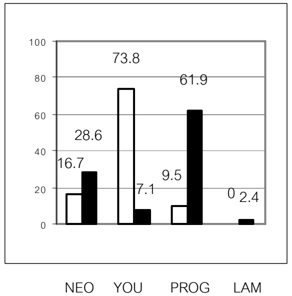
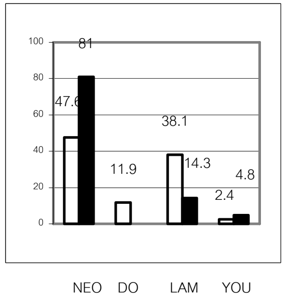
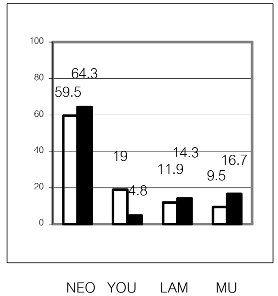
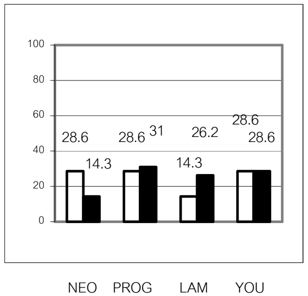
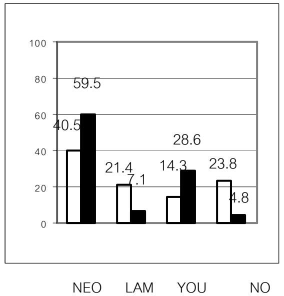
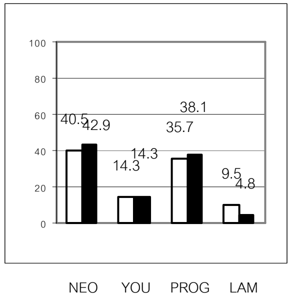
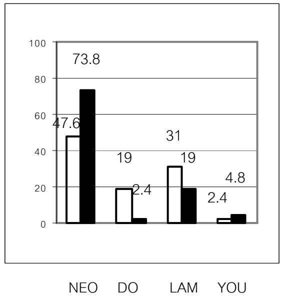
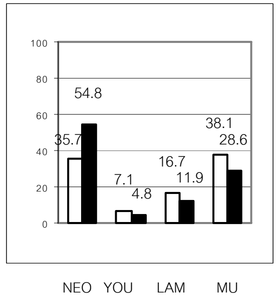
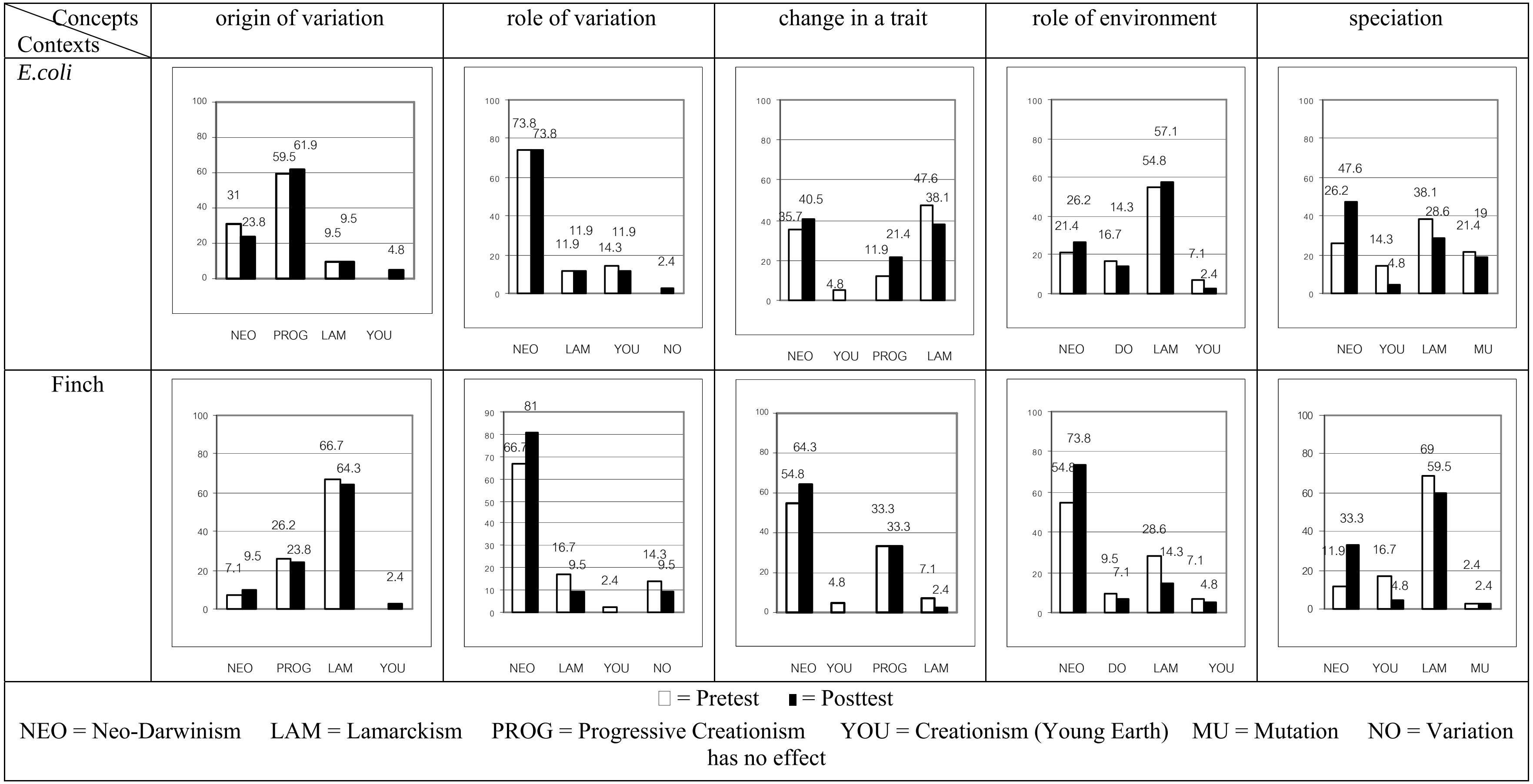
Concepts / Contexts	origin of variation	Role of variation	change in a trait	role of environment	speciation
Bentgrass					
Moth					
Guppy					

Figure 6.41 (Cont'd)



In conclusion, the students had developed scientific understanding of role of variation, role of environment, and speciation after the implementation of ELU. In posttest, there is an increase in number of students who applied Neo-Darwinism to explain these concepts while the number of those using non-scientific models decreases noticeably. However, the students still had difficulty in understanding the concepts of origin of variation and change in a trait, even the teacher had discussed the two concepts in the classroom. The students could not have linked between genetic and evolution concepts. This confirms that student model is resistant to change even after being taught the scientific model. Soyfah found that the students could not answer her question about the origin of frog skin color. This concept must be very difficult for students and resistant to the instruction. Students' prior knowledge and prior concepts plays an important role in their learning. As for change in a trait, the teacher did not emphasize that evolution occurs at the population level and the process of natural selection always took time over generations. Interestingly, only students of Soyfah show the improvement of their understanding of speciation after instruction. When look back at the classroom experience that these students had got, they were encouraged by the teacher to fully engage in ELU activities. The students examined the case studies of the speciation of Galapagos finches and bread wheat and answered the question at the end of the cases. Soyfah discussed the process of speciation with the students. This might have produced desirable effect of student understanding of this concept.

Common Findings Among Cases

The implementation of the ELU

Different teachers had their own way of implementing the ELU. Some of them followed the instructional guidelines of the intervention while some did not. Their content knowledge background and personal belief on effective teaching are found to be critical in implementing the intervention in the setting. Karnika and Soyfah followed the ELU teaching guidelines. They employed the instructional media and materials of the intervention. They gave importance to what the student had brought to the classroom and encouraged them to socially construct the knowledge by involvement in various hands on, group-work activities and whole class discussions. These two teachers also used a variety of assessment techniques to assess student learning. The assessment was done continuously over the period of implementation for the sake of better learning and teaching. The thing that Karnika and Soyfah shared in common is the concern that their own current practice did not attract student attention and enhance scientific understanding of evolution. Karnika came to this study with the expectation that she would get a new teaching strategy that could help her and students develop understanding of population genetics, Hardy-Weinberg Law, and applications of evolutionary theories. Karnika and Soyfah expected that the ELU would adduce student attention and provide constructive learning experience to their students. They willingly tried out a new way of teaching evolution to their students.

Sarapee, however, did not follow the instructional guidelines of the ELU. From the interview before the implementation, she said that the goal of her teaching was to help student pass the entrance examination. She was under pressure. She was expected by the principal and students' parents to help students achieve a place in a public university. Sapapee expected that she would be given a variety of instructional materials and activities from the participation in this study to get students best prepared for the upcoming entrance examination and also attract students' attention.

She had planed to use the ELU as a supplement to her instruction. This is consistent with notion of Badders et al. (1996) that teachers often used the new science program to supplement their current instruction rather than to adapt the new program to meet student need and classroom context. Her attitude and expectation was reflected during the implementation.

At the beginning of the implementation, she tried to follow the lesson plan but in the later weeks, she raised her concern on the entrance examination. She was not sure if the ELU was the right choice for the entrance examination. She thought that the content of the ELU did not cover all the required content of Evolution for the examination. She disagreed with the exclusion of the topic, Human Evolution from the intervention. She was so certain that this topic would be in the entrance examination. That is why she allocated the time for the implementation of the ELU on this topic. In terms of the ELU activities, Sarapee thought some teaching steps were a waste of time such as organizing students to work in groups to test the assumptions of each model of evolution or to solve Hardy-Weinberg problems. She preferred to do and explain it to the students. In the later weeks of her implementation, her instruction had become more teacher-centered in the transmission of knowledge information.

As for Pinsuda, she had faced a lot of difficulties throughout the implementation of the ELU. Pinsuda came to teach evolution by request. She had never taught evolution before. She hadn’t known about its content and teaching strategies. She joined in this study, therefore, with the hope of having a ready-made instructional package with step by step guidelines to help her get over the first year of teaching evolution. She tried so hard to repeat all steps of the ELU using all the instructional media and materials but at many stages, she could not make it as planned because of her limitation of content knowledge. Pinsuda could not explain many concepts, answer students’ questions, or deal with conceptual conflicts during the discussions. This caused her to lose confidence In the later weeks of her implementation, Pinsuda preferred to keep herself away from these troubles by telling students' answer and knowledge, not responding to students' idea, not having a discussion with students, and skipping some topics about which she was unsure. This finding confirms the notion of Wilson, Shulman, and Richert (1987); Shulman (1987); and Hashweh (1987) that pedagogical content knowledge of novice teachers is generally slow and limited.

The teachers in this study have a various degrees of pedagogical content knowledge, "the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students" (Shulman, 1987: 15). This is reflected by the way the teachers implemented the intervention in their classroom setting. It found that the teachers' fragmentary knowledge and misconception affected their awareness of the students' alternative conceptions and acted as obstacles in using student-centered, active learning methods. For these teachers, teacher centered approach is preferred. This is consistent with the studies of Driver, et al. (1994) and Kikas (2004). Driver reasoned that while in a traditional lecturing situation the teachers may rely only on the book, in an experimenting, discussion, or a group work situation, they must be able to answer various questions and clarify conceptual conflicts. This study also found that teachers' beliefs in learning and teaching techniques tremendously affected their pedagogical reasoning skills. This is evident in the cases of Karnika and Saparee. Although Karnika did not have content background as strong as Sarapee did, she followed the ELU successfully and found the implementation of the ELU helped her develop content knowledge and pedagogical skills. Sarapee, on the other hand, found the implementation of the ELU irrelevant to what she had been practicing and therefore, did not follow the guidelines of the intervention. From an in-depth interview conducted before the implementation, Sarapee described her practice as very student-centered. Nevertheless, the observations of her teaching practices starkly contrasted with her belief: she behaved in teacher-centered ways. This finding coincides with those of other studies such as Hashweh (1996) and Simmons et al. (1999), who found that a small number of science teacher believed or realized that students hold alternative preconceptions, and that science learning entails conceptual change and this view was not related to the teachers' years of schooling, years of teaching experience, level at which they taught and teacher specialization.

The obstacles to implementation

University entrance examination

The entrance examination has become the first priority of upper secondary education in Thailand. In each year, more than a hundred thousand high school students are competing in a nation-wide examination to enter state universities. However, only some forty five thousands would succeed (Bowarnkitiwong, 2004). This intense competition has a great influence on teaching all subject areas at higher school level. Teaching science, is no exception, it is expected from all parties to prepare students to successfully competite in this examination. Sarapee said that all teachers in her schools were asked by the principal and Parent Teacher Association (PTA) to prepare the students for this tough competition. The number of students who passed the examination was reported to the public and used as one criterion for internal school assessment and the advertisement purpose. In previous years, her instruction, in the last two months before the entrance examination in a particular, had been entirely based on the former tests which were accessible at street book stores. She used these tests to direct her teaching. She thought that by this strategy, her students would be more familiar with the tests and would do better in the examination. Sarapee paid attention only on the topics that, from statistics, were usually in these tests. Non-tested content were usually skipped. The learning outcomes and teaching strategies suggested in National Science Content Standards (IPST, 2002) were not paid any attention. This is the reason why Sarapee found the implementation of the ELU, the active learning-based instruction, were irrelevant to what she had been practicing and decided not to follow the intervention.

This finding is consistent with the notion of Popham, et al. (1985); Bracey (1987); and Shepard (1991) and the studies of Rottenberg and Smith (1990) and

Bowarnkitiwong, et al. (2004) that high-stakes tests narrowed the curriculum: the instruction was focused only on skills and content covered on the test. In the study of Rottenberg and Smith (1990), it found that because of external tests, elementary teachers had given up on reading real books, writing, and long-term projects and were filling all available time with the tested content such as word recognition, recognition of errors in spelling, language usage, punctuation, and arithmetic operations. The case of Sarapee strongly confirmed the findings of Bowarnkitiwong, et al. (2004) who studied the impact of the new entrance examination of Thailand on stakeholders. She collected data from 4,287 Grade 12 students, 1,062 students' parent, 545 secondary teachers, 90 instructors or administrators in public universities, 616 freshmen in public or private universities, 20 owners of tutoring institutes, and 25 educators. The study showed that the entrance examination system had distorted teaching and learning at high school level: the test system made the teachers and students focus only on the entrance examination. Both teachers and students thought that the key to success in the examination was to practice on entrance examination questions as much as possible.

Time constraint

During the implementation of the ELU, there were many days off which shortened the teaching session. For example, all students had to take National Test for two days. This was compulsory for all grade 9 and grade 12 students to take this test. All male students had to go to military training for a week. Grade 12 students of Nanfah School had to participate in school support days for 3 days. The teachers, in addition, could not fully participate in the implementation. One teacher in this study was asked to attend a workshop for a week. The same teacher was also assigned from the head of science department to take students to join in a local science competition for two days. Another teacher was asked to leave a class for a week to prepare material and give a report to an external assurance committee. These days off were generally unanticipated. The teachers all faced time constraints. The schedule had become extremely tight. The teachers felt stressed. Some of them had to set up extra time to compensate the time off while some decided to skip the activities and employed lecturing to summarize the key ideas of the lessons otherwise they could not have completed teaching on time as determined by principal.

The effectiveness of the ELU

Student Learning

The instruction based on social constructivism could help students develop the scientific understanding of role of variation, change in a trait and role of environment. The students still had difficulty in understanding origin of variation and speciation. This conceptual difficulty is partially the result of their classroom experience. The students of all schools had developed scientific understanding of role of variation, change in a trait, and role of environment as the number of students using the scientific model to explain these concepts increases after the instruction. All teachers run the activities of the first three lessons that were dedicated for models of evolution, even though, in practice, the implementation was slightly different. In these activities, the students were encouraged to examine each model of evolution, find out its assumption and make a comparison between models. The teachers asked the students to apply the scientific model to explain the adaptation of plants and animals in mangrove forest and the adaptation of frog skin color. The students were asked to observe the variation within the frog population, its role and the environment working on such variation. The students were encouraged to socially interact with each other and have a discussion to develop their understanding of Neo-Darwinism. This finding is consistent with the study of Passmore, et al. (2001) and Passmore and Stewart (2002) that used modeling approach to teach natural selection to high school juniors and seniors. The modeling approach was based on social constructivism. By this approach, the students were introduced to three important explanatory models in evolution and provided opportunities to use, revise, and assess the models in realistic ways. They found that during the instruction, the students used sophisticated reasoning. The students developed a rich understanding of Darwinism especially the concepts of variation and differential survival (Role of variation) and applied that understanding to reason in a discipline-specific way about evolutionary phenomena.

However, from the test results of this study, the students in all cases did not apply Neo-Darwinism to explain origin of variation. They preferred non-scientific model, Progressive Creationism in both pretest and posttest. When looking at these students' classroom experiences, it was found that none of their teachers, except Soyfah, mentioned about origin of variation during the discussions. These teachers might have not understood the genetic basis of natural selection so they could not connect origin of variation to the process of natural selection. In Soyfah's case, even she discussed about this topic to students, from the conversation, it was obvious that it took a long time for her students to recall the causes of genetic variability that they had learnt in the previous chapter. Many of these students could not give any answers so Soyfah needed to tell them what it actually was. This conceptual difficulty confirmed the findings of many previous studies such as Brumby (1984), Bishop and Anderson (1990), Settlage (1994), Jensen and Finley (1996), Anderson et al. (2002) and Moore, et al. (2002) that the students could not explain the sources of genetic variation in a population and could not establish a link between this genetic basis to the process of natural selection even after the formal instruction.

Another consequence of classroom experience is the understanding of Speciation. Only Soyfah's students developed a scientific understanding of Speciation. There is a shift in the most common model from non-scientific to scientific in almost all contexts and the increase in the number of students applying the scientific model in posttest. Soyfah is the only teacher in this study who followed the ELU in this topic even though she had to teach it in an extra time. She first asked students what species mean to them, discussed various definitions of species and why a species did not interbreed with other species. Then, she assigned the students to work in groups to identify the types of reproductive isolating mechanism from given statements. At the end of the lesson, she asked each group to explain the mechanism of speciation of one of the four cases of organism; by allopatric or sympatric speciation. As for the other teachers, they gave a lecture based on the information in the teacher manual. They did not let students to do any activities of the ELU in this lesson and had no discussions on the mechanism of speciation.

The students used a model of evolution inconsistently to explain concepts of evolution especially change in a trait and speciation. For these two concepts, one model was more preferable for a particular context. Their explanations derived from their personal experience and worldviews. The inconsistent use of model across different contexts is found in change in a trait and speciation in all case studies. Change in a trait, for instance, the majority of students used Progressive Creationism in Moth but Lamarckism in *E .coli* and *Bentgrass*. They explained that the black wing peppered moth evolved from the original God-created white wing moths by unknown process: some students said that the process was likely mutation. Interestingly, the same students preferred different models, Lamarckism to explain the changes in coppered tolerant capacity in bentgrass and antibiotic resistance in *E. coli.* They thought that bentgrass and *E. coli* accumulated such abilities gradually in their life span and could transfer the abilities to their offspring. This inconsistence of use of models across different contexts is found commonly in all cases. Therefore, it could be argued that the students preferred to apply Progressive Creationism to explain a macroscopic and morphological character (moths' wing color) but Lamarckism for a microscopic and physiological character. This finding is consistent to that of Rowe (2004) who found that student explanations of antibiotic resistance in bacteria incorporated Lamarckism. The use of these models in these contexts is logical and reasonable to the students. The inconsistence of use of models found in this study confirms the notion of Wood-Robinson (1994: 45) that, "the belief in the inheritance of acquired characteristics is common, but the strength of the belief may dependent on the context. In many cases, students may think that this only applies if the features are repeatedly acquired over a long period of time"

When one examines their reasons carefully, it is found that the students had employed their own personal experience and worldviews to explain the new situations. For instance, one student gave the reason why he used Lamarckism over bentgrass and *E. coli* that the characters of the two organisms were very similar to the immunological response in human body which was a gradual process and best explained by Lamarckism (he did not state the name of the model). Therefore, the change in *E. coli* and bentgrass should be explained in the same way. Apparently, his reason is anthropomorphic; he had attributed human characteristic and quality to non-human beings. The use of model of students in this study supports the notion of Driver et al. (1985) on student conception that students initially based their reasoning on observable feature and called upon different ideas to interpret situations which a scientist would explain in the same way. Some of their ideas are prevalent and transferable across various topic areas. These ideas were derived from world views. In the context of evolution, the models of Creationism and Lamarckism were derived from students' world views of teleology and anthropomorphism respectively. The finding of teleological and anthropomorphic worldviews in this study coincide with that of many previous studies such as Bloom (1989); Tamir and Zohar (1991); Robinson (1994); Anderson et al. (2002); Moore et al. (2002).

The ELU captured the students interest. The students paid more attention to the lesson. The students understood and did the the ELU activities. The students in all cases paid more attention to the lesson than ever before. They found the ELU activities interesting, meaningful and helpful. The students from all groups of learning ability understood the activities and could run them correspondingly and enjoyably. The low achievers, in a particular, had changed their behavior in a desired way. They gave cooperation to the teachers and concentrated on their work. No groups went off track as always. The students loved to engage in hands on activities and work with their peers. Many students said they were looking forwards to studying evolution. They said the ELU activities helped them develop an understanding of evolution. The activities gave them a clear insight about abstract and difficult concepts such as those of population genetics and Hardy-Weinberg Law.

They felt they had taken a part in learning. It was good to be able to discover the knowledge actively.

<u>Teacher learning</u>

The implementation of the ELU enhanced teachers understanding of evolution and pedagogical skills. The teachers gain more confidence in teaching evolution after the implementation. Karnika and Pinsuda, before the implementation, admitted that they had not been clear about population genetics such as alleles, genotype, phenotypes, allele frequency and genotypic frequency and Hardy-Weinberg Law. In previous years, Karnika had taught these concepts by giving the definition of each term and the example of the calculation from the textbook but could not explain it to the students. Pinsuda had never taught evolution before. She was so worried if she could explain the concept of evolution and ran the ELU activities. Both teachers said that running the ELU activities helped them understand evolutionary concepts because they had to study the content in the information section and the guidelines before doing the activity very well in order to explain the concepts, run the activity and responded to student enquiry. The teachers said that attending a weekly meeting during the implementation helped them improved understanding of evolution and its pedagogy a lot. In the meeting, they were informed about the concepts that they had misunderstood and explained to students incorrectly as well as the activities that they had run wrongly. Karnika said that, in the meeting, she could reflect what she had done, share the problems and she got the practical solution out of the meeting. She said that she felt thankful to find out such mistakes. She said that they had brought correct concepts back to the class and discussed them with students.

As for experienced teachers like Soyfah and Sarapee, they found that the implementation of the ELU gave them practical ideas to make evolution lessons lively and enjoyable to students. All teachers said that the ELU activities would draw student attention to the lesson. The students were keen to participate in the active and collaborative activities. Sarapee and Pinsuda noticed that their students gave more attention to the lessons than ever before. Many of those misbehaving had changed their behaviors in a desirable way. This positive change convinced and motivated Sarapee, who had preferred to be a spoon feeder over the years, to use constructivist teaching more in her instruction. Implementing the ELU also made Sarapee realize her weak points in lecturing. In the Making a Fossil activity, many groups of students could not conduct the experiment properly. She said that the students did not have much opportunity to do experiments as they had done in lower secondary level. Hereafter, she would put an emphasis more on the science process skills in her teaching.

Summary

After the implementation, students improved their understanding of evolution in role of variation, change in a trait and role of environment. Social constructivism which underpins the intervention successfully enhances student understanding of these three components of natural selection. As for origin of variation and speciation, it indicated that their classroom experience; the way they were taught, was the primary source of the conceptual conflict. It also found that the ELU could capture student interest. The students paid more attention to the lesson than ever. They were able to run all activities and did them enjoyably and actively.

Teacher implemented the ELU differently. Their content knowledge and beliefs in teaching and learning were the important factors determining the way these teachers implemented the intervention in the classroom setting. The teachers who did not have strong content background could not run the activities and explain the concepts of evolution to students. The teacher who thought that teaching should equip student to do best in the examination paid much of their attention on tested content and transferring knowledge. On the contrary, the teachers who had strong content and wanted to improve their current teaching practice were found to give their cooperation in trying out the intervention. The process of implementation provided the teachers opportunity to improve pedagogical content knowledge. In weekly meetings, they were given encouragement and continuous support in a safe and friendly environment. The following, the last, chapter will discussed the conclusion of whole study, the implication of the study and suggestion for future research.

CHAPTER VII

CONCLUSIONS AND IMPLICATIONS OF STUDY AND SUGGESTIONS FOR FUTURE RESEARCH

Introduction

This chapter is centered on research findings and their implications to the science education research community. The research framework is first reviewed for the sake of discussion. Subsequently, the conclusions of each phase of study are discussed including the Thai students' understanding of evolution and the situation of teaching and learning evolution in Thailand explored in the first phase and the implementation of the Evolution Learning Unit and the effect of the intervention on student understanding of evolution in the third phase. At the end of this chapter, some suggestions for future research are provided.

Review of Research Framework

This research was divided into three phases: Exploratory Phase, Intervention Design and Development Phase, and Intervention Implementation and Evaluation Phase. In the initial phase, student understanding of the fundamental concepts of evolution, evolution process, and students' and teachers' opinion on the existing situation of teaching and learning evolution were investigated. The instruments; the Evolution Fundamental Concept Test (EFCT), Evolution Diagnostic Test (EDT), Current Situation of Teaching Evolution (CSTE) questionnaire were administered with 253 Grade 12 biology from three schools in Bangkok and Nontaburi at the end of January 2004, after the Evolution Unit oriented by the former curriculum was finished. The teachers of these students were also in–depth interviewed about the existing situation of teaching and leaning evolution. The implications of the findings of the exploratory phase were used as one of guiding principles in designing and developing an intervention, the Evolution Learning Unit in the second phase of study which lasted from March to October, 2004.

In the final phase, Intervention Implementation and Evaluation, the intervention was implemented in three schools by four biology teachers in January 2005, second semester, academic year 2004. The schools and three of four teachers had participated in the first phase of study. In this phase, the implementation of the ELU by the teachers and the effect of the intervention on student understanding of evolution were investigated. Multi-site case study with multiple data gathering methods was employed for the third phase. The research framework is summarized in Figure 7.1.

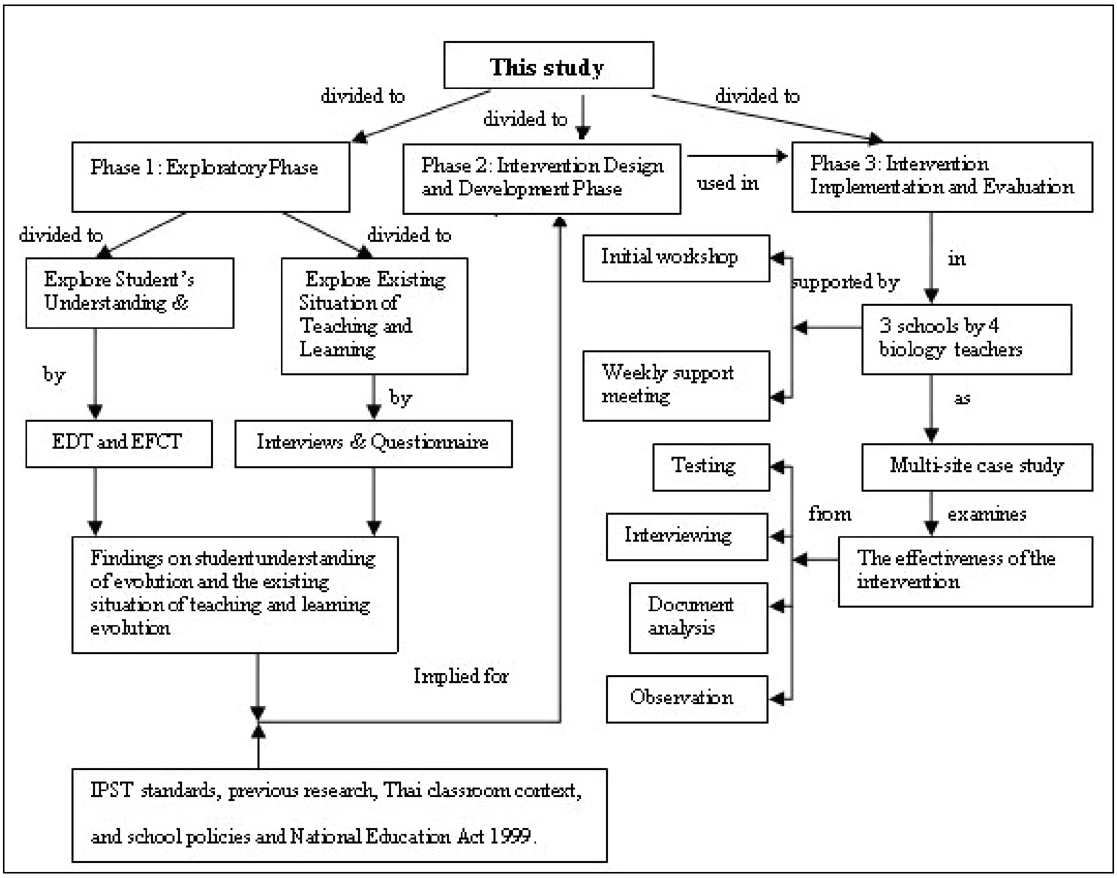


Figure 7.1 Research framework

Conclusions of the Study

First Phase: Exploratory Phase

Thai students' understanding of evolution

From the test results, it found that the majority of students had difficulties in understanding evolution. The students did not have a scientific understanding of the fundamental concepts of evolutionary process even after they had been taught these concepts previously in the Genetics and Ecology Units. In the case of the concepts of genetic variation and adaptation, in particular, the majority of students preferred to apply non-scientific models in all contexts of question. The students consistently applied Lamarckism the most to explain adaptation in all contexts. This common use of Lamarckism to explain adaptation coincides with the findings of Engel Clough and Wood-Robinson (1985), Bishop and Anderson (1990) and Wood-Robinson (1994) that the students referred to adaptation as non-inheritable changes acquired within the life-time of an individual in response to the environment. They did not think that adaptations were heritable changes that occurred in populations over time; they have a genetic basis and are passed on from one generation to the other, via natural selection. Like the previous studies, this study found that the students used anthropomorphism in their Lamarckian explanations; treating animals or objects as if they had human quality. In their written explanation, some students explained adaptation in terms of animals "willing" survival by considered effort, "wish", "tried" or "strived" for particular ends.

The common use of non-scientific models to explain the concept of genetic variation found in the exploratory phase confirmed the findings of Bishop and Anderson (1990) that the students were not aware of genetic variability in a population. Bishop and Anderson (1990) and Ferrari and Chi (1998) emphasized that the awareness of genetic variation and its role in a population was essential to understand the process of natural selection. Without such understanding, the students would apply Lamarckism in their explanation. This notion was true for this study since the majority of students preferred Lamarckism to explain the concept of change in a trait: the whole population changed gradually and equally rather than only those with favored trait to the existing environment. Ferrari and Chi stated that the use of non-scientific model to explain evolutionary process related to the inherent difficulty of underpinning concepts such as genetic variation, population, frequency, gene, and species.

In regard to students understanding of evolutionary process, the target concept, the majority of students preferred non-scientific models; Progressive Creationism and Lamarckism, to explain concept components of evolutionary process even after they had just been taught by their teachers. The percentage of students using non-scientific model to explain the concepts of origin of variation, change in a trait, and speciation was much higher than that of scientific model. This preference of non-scientific models to explain evolutionary process confirms the findings of Bishop and Anderson (1990) and Settlege (1994). Like the students in the previous studies, the students in the current study could not explain the sources of genetic variation; mutation and genetic recombination; the raw material of change that national selection act upon. They could not explain survival or disappearance due to natural selection.

The data of student understanding of the fundamental concepts of evolutionary process and the concept components of evolutionary process profiles the use of models in varying contexts of questions. It found that students' use of model to explain these concepts was dependent on the contexts of questions. For a particular context, the students preferred a particular model of explanation to the others. Noticeably, the students tended to apply the same model to similar contexts (microscopic or macroscopic character). For example, the majority of students preferred Lamarckism to explain copper tolerant capacity of bentgrass and antibiotic resistance in *E. coli*. In these two contexts, the characters are both microscopic and repeatedly acquired or accumulated in organisms' lifespan. Interestingly, this pattern was also found with students in all cases in pretest of the third phase of study. The inconsistent use of model across different context of questions coincided with the notion of Wood-Robinson (1994) that the strength of a particular model was dependent on the context. In many cases, students may think that Lamarckism, for example, only applies if the features are repeatedly acquired over a long period of time. When the students were interviewed about their reasons for picking up a particular model for a particular context, the influence of their personal worldviews and prior experience were revealed. The students who had chosen Lamarckism tended to use anthropomorphism in their reasoning while those using Progressive Creationism tended to use teleology. The students tended to transfer the model that had been successfully applied in the past to a similar context in the present.

The situation of teaching and learning evolution in Thailand

As for the existing situation of teaching and learning evolution, the findings from the Current Situation of Teaching Evolution (CSTE) questionnaire and in-depth interview with teachers indicate that teaching evolution in an academic year 2003 was not aligned with the goals of National Science Curriculum Standards in many ways. In terms of textbook, the teachers attached to the national textbook using it as a primary resource of teaching and learning evolution. In this textbook and a teacher manual, there were no learning activities suggested. There were no instructional media or material available. The teachers reported that they had no direction to teach evolution so they had to employ lecturing. This is consistent with the students' opinion. Around seventy percent of students reported that their teachers use lecturing to teach all topics of evolution. In company with the lecturing, the teachers assigned a group of students to study, do a report and deliver classroom presentation on a particular topic of evolution. One teacher said that she preferred teaching evolution this way because the content of evolution was not difficult. The students could study and come up with understanding on their own. Another teacher thought that evolution was not as important as other topics of biology because its low proportion in the entrance examination. She believed that recapping the key ideas and encouraging the students to the former entrance examination was the most effective and successful way of teaching evolution. However, many students found listening to a lecture and doing a report and preparing a classroom presentation boring and did not stimulate their learning. All teachers noticed students' low attention to the lesson. The students reported that the teachers did not explore their ideas about the concept before teaching. The teachers rarely had a whole class discussion on evolution as reported by less than fifteen percent of students. Less than five percent of them reported that had engaged in hands on activities. The students wanted more hands on, fun, challenging, and cooperative activities so they could engage more actively in learning process. All teachers did not review fundamental concepts of evolution such as population, genetic variation, gene, allele in Evolution Unit. They thought that the students must have understood the concepts because they had already learned them from the previous units. All teachers thought that Hardy-Weinberg principle was the most difficult topic of evolution to students because it was involved with calculations and requires students to have sound understanding of basic genetic concepts such as gene, gene pool, allele, genotype, and phenotype. On the other hand, the majority of students thought that the application of the models of evolution was the most difficult. They asked the teachers to give examples of applying the scientific model to explain evolutionary phenomena.   One teacher said that she was unclear about the concepts of population genetics and Hardy-Weinberg Law and she wanted to overcome these conceptual difficulties and could teach the concepts with more confidence.

In summary, the instruction was probably based on fact and memorization rather than enhancing students' scientific understanding and often driven by the entrance examination. The teachers did not establish a link among topics of evolution and between evolution and other related areas. The factors determining teachers' instruction include the availability of learning activities and instructional media and materials, their value of the subject, and content knowledge. The teaching strategies that the teachers had been using could not help students develop scientific understanding of evolution and attract student attention to the lesson.

<u>Second Phase: Intervention Design and Development</u>

In the second phase, the Evolution Learning Unit (ELU) was designed and developed. The ELU is a ready to use instructional package for the teaching of Evolution of Grade 12 biology. The goals of this learning unit are to enhance scientific understanding of evolution, create attractive lessons, and happy learning environment to students. The design and development of the intervention was guided by student understanding of evolution and existing situation of teaching evolution explored from the first phase of study, the guidelines of content and the development of school science programs of National Science Curriculum Standards, successful teaching strategies from previous research, and Thai educational context.

The content of evolution was organized into 3 consecutive themes; models of evolution, microevolution and macroevolution. The themes are sub-divided into 7 lessons; Development of Models of Evolution, Models of Evolution, Evidence for Darwinism, Population at the Equilibrium, Evolving Population; Speciation and Macro evolution. The ELU takes 12 periods of 50 minutes or one full months (3 periods per week) to complete. The materials of the ELU comprise lesson plans; student manual including information about a concept, worksheet, self assessment form; and instructional media including colored transparencies, videotape, tape cassette, models, and tool kits. In each lesson of the ELU, the students engage with a variety of hands on activities asking student to be actively involved in the activities. The interaction within a group of students and the interaction during a whole class discussion are the key learning strategy underpinning all activities of the ELU.

<u>Third Phase: Intervention Implementation and Evaluation</u>

The implementation of the Evolution Learning Unit

Different teachers implemented the ELU differently. Some of them followed the instructional guidelines and made use of all instructional materials while some did not. All teachers felt unfamiliar with trialing the ELU at the beginning of the implementation because it was quite different from the way these teachers had taught evolution in previous years. In later weeks, the teachers had adjusted themselves and felt more comfortable and confident in implementing the ELU. The students noticed that their teachers had changed teaching behaviors. The teachers asked more questions and encouraged classroom discussion. Some teachers adapted the unit to meet student needs and classroom context for a better learning. One teacher in this study, however, did not follow ELU. Although she made use of all instructional materials, she used them in her own way. Recapping the key ideas and asking students to do former entrance examination were her prime teaching strategies. She believed that these strategies would help the students pass the entrance examination. All teachers in this study had to work under pressure in the constraint of time. They were all expected by the school administrators and students' parents to help the students pass the entrance examination. The number of students passing the examination were used an indicator of school quality control or used for the sake of school advertisement. Teachers' content knowledge is another determining factor of teachers' different practice. The teachers who did not have strong content knowledge of the subject matter faced difficulty in explaining evolutionary concepts, dealing with conceptual conflicts in a discussion and running the activities. Models of evolution, Hardy-Weinberg principle and the integration between evolution, genetics and biodiversity are the three topics in which the teachers were the least confident.

The effect of the intervention on student understanding of evolution

As for student learning outcomes, it found that after instruction, there was an increase in using the scientific model in the concepts of role of variation, change in a trait, and role of environment. In some contexts, there was a shift of most common model from non-scientific models in pretest to the scientific model in posttest in these concepts. Origin of variation and speciation, however, are two concepts that the majority of students still applied non-scientific model even after the instruction. This persistence of non-scientific model is consistent with findings of Desmastes, et al. (1995), Jensen and Finley (1996) that conceptual change about evolution was not easy to bring about. The concept of origin of variation, in a particular, it was evident that the students had been taught this concept in both Genetics Unit and again in Evolution Unit. In the case of Soyfah, however, her students could not choose the scientific explanation in test. Like the previous studies, although there was an increase in the use of scientific models for evolution after the instruction, there were few reductions in the use of non-scientific models. Non-scientific model was resistant to the instruction.

This persistence of non-scientific model might be the consequence of the instruction that some teachers did not establish a link between evolutionary related concepts (origin of variation) and give an opportunity to students to engage in the activities to construct the knowledge (speciation). From the interviews, many students could identify the sources of genetic variation but they did not know this genetics concepts was one of the concept components of evolutionary process. This might be the effect of fragmented instruction and the former curriculum that assigned biodiversity, evolution, and genetics to separate chapters in different grade level. In the concept of speciation, only one teacher followed the ELU. This teacher probed student understanding of the concept, encouraged the students to identify reproductive isolating mechanisms, study the case studies of the speciation of Galapagos finches and bread wheat and do the exercise about the case studies. By this fashion, the students were given an opportunity to clarify, verify and exchange their ideas.

Meanwhile, the other three teachers focused the key ideas of speciation and the definitions. The students of these teachers, therefore, did not have a chance to reflect on their understanding. Their non-scientific understanding were not challenged and corrected. This has a great influence on student understanding of evolution. In posttest, only the students of the teacher who had followed the ELU showed an increase in the use of scientific model in all contexts while those of the other teachers still preferred to use non-scientific models to explain the concept.

Implications of the Study

Implications for teaching and learning evolution

The findings on student understanding of evolution and the existing situation of teaching and learning evolution give the implication for teaching evolution. Teaching evolution is to teach students a model in science. Before studying models of evolution, the students should first understand a model in science and be able distinguish it from other types of scientific knowledge. The students should also understand the nature of scientific explanation: use of logically consistent arguments; emphasis on evidence; use of scientific principles, models, and theories; acceptance or displacement of explanations based on new scientific evidence. This understanding is necessary for characterizing and evaluating models in science. To promote scientific understanding, the instruction should put emphasis on developing a true understanding of the key explanatory models in evolutionary biology; Creationism (young earth), Progressive Creationism, Lamarckism, and Neo-Darwinism. The students should clarify and verify their initial models. They then should examine the key models of evolution, make comparison between models and evaluate the model. The students should expand their scientific models to explain various and real evolutionary phenomena.

It is advisory for the teachers to facilitate the interaction between a teacher and students and between students and students in classroom. Within a social group, the students can shape the kinds of interpretive process available to individuals by interaction with others in face-to-face discussions involving argumentation, contradiction, negotiation, decision, judgment, and problem-solving activities. By this fashion, the students would learn both the key knowledge claims of evolutionary biology as well as the processes by which such claims are generated and justified.

Implications for the implementation of a school science program and the professional development for in-service science teachers

The findings have implication for the implementation of a new science program in a school system and professional development of teachers of science. To succeed in implementing a school science program, the teachers should be given an opportunity to reflect on their current teaching, problems about teaching and learning, and give suggestions. The rationale of a new way of teaching needs to be discussed. The sound argument with the empirical evidence could effectively challenge and convince the teachers who have hold different beliefs on teaching and learning for years to trial the new teaching approach.

Before the implementation, it is a must to review with the teachers the subject matter of the intervention. From this study, for instance, the teachers had said that they had not had any problems about content of evolution. However, when they came to teach, almost teachers faced difficulties to explain the concept, deal with students' idea, and run the activities. Some teachers held misconceptions and delivered it unintentionally to the students. Experienced teachers may be reluctant to say that they are not clear in what they have taught for years. But this must not be overlooked in the initial workshop as well as the understanding of the activities of intervention. In the workshop, the teachers should experience and try out the activity with their own hands. The discussion should consider how suggested activities enhance student understanding. The teachers and the curriculum developer also need to negotiate and decide on how the curriculum will be used with students. This would develop the idea of partnership and ownership between the teachers and a curriculum developer.

Throughout the implementation, continuous support must be provided for the teachers. From this study, the teachers said that the weekly teacher support meeting were helpful for them since it was the safe place where they could reflect on what they have done and learnt from the implementation, speak out their problems, and receive suggestions from the mentor and other teachers.

Curriculum implementation can serve as a professional development opportunity for teachers of science. Curriculum implementation relies on teachers having access to high quality curriculum materials developed by people with expertise in content and pedagogy, as well as sufficient resources and time to design and refine the materials for use in classrooms with diverse students (Loucks-Horsley, 1996). Through implementing the curriculum, reporting on what happen, and reflecting with others on different ideas and activities, teachers learn about their own teaching and their students' learning (Cohen and Hill, 1998).

Data from teacher's educational background in this study show the lack of preparation of content of evolution in a higher education level. In a long run, there should be a reform in curriculum and instruction in a pre-service biology teacher education. From the interviews with the teachers, there was no evolutionary biology course available at university level in their time. This is still true for many institutions in Thailand in the present. Evolution is only a topic in general biology. Most of the teachers had to study on their own from IPST teacher manual when they came to teach this topic. Although there is a coursework in evolution provided in some institutions nowadays, it is not obligatory for biology education majors. Evolutionary biology should be a core and compulsory course for these prospective biology teachers. The promotion of the scientific understanding of evolution should be goals of any college biology departments. The quality of the instruction in universities is another concern. College science teaching should also be reformed since it is a template for teaching science in lower levels. The instruction should put more emphasis on scientific inquiry as a tool for learning science and facilitate the interaction between lecturers and students and between students and students instead of mastering the science content by telling and remembering fashion.

Suggestions for Future Research

To extend this study, the researcher would like to recommend the following issues for a future investigation.

1. A follow up study should be first done. The study should follow the four teachers in the following academic year or two to see how they teach evolution. This would show the effect of this implementation on teacher's practice in a long term. A number of questions arise and need to be investigated: if the teacher develop Pedagogical Content Knowledge (PCK) in second year of implementing the intervention; if they feel more comfortable to teach and can run the ELU activities on their own; how their previous experience of implementing the ELU helps them teach evolution more efficiently in following years of teaching evolution, what kind of support the teachers need in the second or third year of implementation etc.

2. There will be a revision of the Evolution Learning Unit and the process of implementation of the unit for a future wider use. For example, in the initial workshop, there will be the session on reviewing teachers' content of evolution and letting the teachers take the role of students to trial the activities. There will be more integration of genetics, evolution and biology in Grade 12 Biology. In doing so, the conceptual framework showing the connection between these three areas will be presented and discussed in the first place. The teachers and students will discuss how genetics, evolution, and biodiversity are related to each other. The teachers should keep referring to this framework, letting the students know where they are up to, where they have passed and where are going to talk about. Some intervention materials will be improved for more efficient use such as buttons, tape recordings and changes to other materials that are available on the local market with lower cost. This study with these improvements should be repeated to examine the effect of the revised

intervention and process of implementation on students understanding of evolution and teachers' learning.

3. Future research needs to be done with other contexts. All schools participating in this project are located in Bangkok and its neighboring province in the central region. The future study should be carried out in other settings with more diversity of schools; school size, socio-economical backgrounds, and culture in other parts of the country. The context of the study might affect the way the intervention is implemented and how teachers and students understand about evolution. For example, in the deep south of Thailand, the majority of people are Muslim. Like Christians, the Muslim strongly believed in God. The research should investigate if this belief affected students' understanding of evolution.

4. The future research should be done to investigate the effect of curriculum implementation on the growth of pedagogical content knowledge (PCK) of teachers. It was evident in this study that the implementation of the Evolution Learning Unit gave professional development opportunity to the teachers. Many teachers gained better understanding of evolution as well as teaching techniques during the implementation. However, this study gives attention mainly on student learning not teachers'. The future research should trace the growth of PCK of teachers before, during and after implementing the ELU.

5. From a number of previous studies (Dagher and BouJaoude, 1997; National Academy of Sciences, 1998; Rudolph and Stewart, 1998; Rutledge and Warden, 2000; Passmore and Stewart, 2002), it found that teaching evolution could enhance students' and teachers' understanding of the nature of science. The teaching of evolution offers teachers and students a superb opportunity to differentiate science from other forms of human endeavor and understanding. Therefore, there should be a study to examine the effect of the Evolution Learning Unit of this study on teachers' and students' understanding of the nature of science and investigate how historical context, model based instruction of the intervention foster such understanding.

Contribution of This Thesis

Student understanding of evolution is more complicated that we could imagine. The students hold many models of evolution and selected the one that sounds most reasonable to them for a particular evolutionary context and concept. Genetic content knowledge is essential to understand evolution. The genetic concept of origin of variation, in a particular, is found to be resistant to instruction. However, the scientific understanding of other evolutionary concepts could be fostered by social constructivism. Student-student and student-teacher interactions during group and whole class discussion in combination with curriculum materials could challenge students' initial non-scientific model, address its difficulties, and show the ways in which the scientific model was more appropriate. By this process, the students also developed understanding of nature of science. This approach would be applicable for teaching other historically rich topics such as photosynthesis, genetics in biology, atomic structure in chemistry, solar system in astronomy. Not only students in activity-based programs of this study have gained scientific understanding of evolution, they also have exhibited increases in motivation to learn, creativity, positive attitudes toward science, perception, logic development, communication and social skills, and higher order thinking. Hands on science make science fun for both the students and teachers. This enjoyment of science learning seems a worthy goal to be considered in choosing instructional approaches in science.

Curriculum implementation helps the teachers address National Science Curriculum Standards for teaching evolution in their school based curriculum by providing information about current evolutionary theory, and by compiling resources and ideas for effective classroom exercises. Additionally, it is evident in this study that the process of curriculum implementation can provide professional development opportunity to the teachers. It is through collaboration and reflection on their teaching and their students' understanding that teachers continue to grow pedagogical content knowledge. Planning and sharing with a colleague during weekly support meetings, centering conversations on student learning and their classroom experience are some ways to encourage reflection on their understanding of subject matter and teaching practice.

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APPENDIXES

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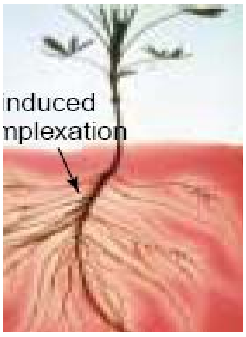
Appendix A: Evolution Fundamental Concept Test (EFCT)

Your answers to these questions will assess your understanding of evolution.
Please choose the answers that best describe your own idea about each question.

Cluster Roots: An Underground Adaptation for Survival in Extreme Environments

Cluster roots are bottlebrush-like clusters of rootlets with limited growth that arise from the pericycle opposite the protoxylem poles along the lateral roots in many species of the Proteaceae. In many cases, members of this family are slow-growing sclerophyllous shrubs and trees, and a major component of the Mediterranean flora in Western Australia and South Africa. They are adapted to habitats of extremely low soil fertility, such as highly leached sands, sandstones and laterites, with phosphorus (P) as a major limiting nutrient for plant growth. Cluster roots have been functionally linked with an efficient chemical mobilization of sparingly soluble soil P source by organic chelators and ectoenzymes released in the rhixosphere of the root cluster in extraordinarily high quantities.

(Günter Neumann and Enrico Martinoia, 2002)



The cluster roots of *Hukea undulata*, a species of Proteaceae

1 What is the population of *Hukea undulate*?
- A. A number of the plants, soil, nutrients and water.
- B. The concept of population can not be applied to *Hukea undulate* because they are plants.
- C. All individuals of the plant in the same area where they can interbreed with each other.
- D. All plants anywhere in the world which are similar to the plant in the picture.

2 What shows genetic variation within a population of *Hukea undulate*?
- A. Some plants are able to mobilize soluble Phosphorus while others can not.
- B. The mature plants can better mobilize soluble Phosphorus than the seedlings.
- C. If we plant the same plant in the two different areas, rich and poor soil, the plant will mobilize phosphorus at a different rate.
- D. This plant can more mobilize phosphorus than that plant because it was more often watered.

3 Which is the fittest *Hukea undulate*?
- A. The one that know how to adapt to the low Phosphorus soil.
- B. The one with widest diameter.
- C. The oldest tree.
- D. The one with Phosphorus mobility.

4 How do the plants adapt to an extremely low soil fertility environment?

A. The plant gradually accumulates the capacity over generations.
B. The capacity originally exists in the plants.
C. Individuals with the capacity can better survive and reproduce more fertile offspring than those without it.
D. The plants considered that they need to adapt in order to survive in that environment.

5 The plants remain in the species of *Hukea undulate*? If they….

A. can interbreed with *Hukea undulate* and produce fertile offspring.
B. Share all resources with *Hukea undulate.*
C. Distribute in the same geographical range as *Hukea undulate.*
D. look like *Hukea undulate.*

Galapagos Giant Tortoises

The giant tortoise is probably the best known of all Galapagos animals. They are thought to belong to just one species, ***Geochelone elephantopus***, with 14 different races or sub-species, three of which are believed to be extinct. It is likely that all the present races of giant tortoise evolved in Galapagos from a common ancestor that arrived from the mainland, floating on the ocean currents. Once the tortoises spread around the archipelago, they evolved on their isolated islands into the different races we see today, some with domed carapaces (shells), and others with saddleback carapaces. The different shapes probably evolved as an adaptation to the particular environment of each island. The large domed tortoises are found mainly in the highlands where there is plenty of food to support their great size. In contrast, the saddleback races live on lower, more arid islands such as Española where food is more scarce and a smaller body is an advantage.

(Adapted from http://www.gct.org/tortoise.html)

Galapagos giant tortoise

6 What is the population of Galapagos giant tortoise?

A. All tortoises in the Galapagos islands.
B. All tortoises in the same island which can to interbreed actually and potentially.
C. All tortoises anywhere which are similar to the one in the picture.
D. All tortoises, their food, and territory.

7 Which is the example of genetic variation within a population of Galapagos tortoises?

A. Unlike the old tortoise, a new born tortoise has a small carapace.
B. In each island, the tortoises have different body weights depending on individual diet and exercise.
C. The serious injury from fighting and natural disaster has disabled some of them.
D. In each island, there is a great variety of carapace shape, from very large dome to smaller saddle-shaped shells.

8 Which one is the fittest in the lower, more arid islands?

A. The tortoise with a biggest carapace.
B. The tortoise with a biggest brain volume.
C. The tortoise with the longest life span.
D. The saddleback tortoise.

9 How did the tortoise in the highlands evolve the large domed carapace?

A. To best survive in the highlands, they realized that they needed the large domed carapace and they did it.

B. The tortoises with the largest carapace survive and reproduce better than those with saddleback carapace so they increased its number over time.

C. The tortoises with saddleback carapace lifted up their back everyday, so their back became larger bit by bit.

D. The tortoises with large domed carapace originally exist in the highlands.

10 What is correct about the races of the Galapagos giant tortoise?

A. All races of the tortoise in the Galapagos are considered to be different species because they are all different in size and shape of carapace.

B. All races are in the same species because they can still interbreed.

C. All races in the same island are the same species because they occupy the same geographical area.

D. Each race is considered to be a separated species because all individuals of that race share environmental requirements.

Black Robin: An Endangered Species

The black robin was once the most endangered species in the world. In 1976, the numbers of the bird dropped to seven, with only two females remaining because their tiny scrub habitat in Little Mangere had been almost completely destroyed. A decision was made to transfer the birds to Mangere Island and South East Rangatina. A cross-fostering program was introduced to increase egg production two or threefold. The eggs were removed and given to a foster parent of another species (Chatham Island warbler in Mangere or Chatham Island tomtit in South East Rangatina) to hatch and raise to independence (only with Chatham Island tomtit). Back fostering was then launched to solve an imprinting behaviour with the foster parent. The birds successfully settled in their new home. Old Blue (who lived to 13 years – more than twice the normal age) and permanent partner Old Yellow (The only viable male of the two then remaining alive) would prove to be an effective breeding pair. All 150 black robins alive today are descended from them. Old Blue saved the species.

(Adapted from Morris and Smith, 1995)

Black Robin (*Petroica traversi*)

11 Which following statement is considered to be the population of black robin.

A. All black robins in south east Rangatina, in which they can interbreed.

B. All black robins in Mangere islands, its territory, nest and foster parents.

C. The black robins and their foster parents.

D. All birds that look like that in the picture anywhere in New Zealand.

12 What is the genetic variation within a population of black robin?
A. There is a variety of feather colour among black robin.
B. Only the chicks fed by the foster parent will survive.
C. In a nest, a few of chicks are bigger than others because the big chicks are fed more.
D. There is a variety of ages in the birds in each island.

13 Which is the fittest black robin?
A. The biggest bird.
B. The bird with the longest life span.
C. The bird that have traits suitable to the environment in Mangere.
D. The smartest bird.

14 How did black robins adapt themselves to the new environment?
A. The birds themselves considered they need to adjust and they did it then.
B. The birds with more suitable traits increased their proportion in a population.
C. The birds daily exercised or stretched on particular organ so that organ became stronger and bigger.
D. The bird did not adapt; they already have perfect traits.

15 How did ornithologists classify the black robins as *Petroica traversi*?
A. They looked at the morphology. If the birds are similar, they are the same species.
B. They look at their geographical distribution. If they are scattered in the same area, they are the same species.
C. They will look at their reproductive isolation. If they can not interbreed with each other and rise fertile offspring, they are different species.
D. They will look at their ecological need. If they share food sources and habitat, they are the same species.

Canary Island Lizards

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent (Thourpe & Brown, 1989). Because of this, scientists assume that the lizards travelled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

(Anderson et al., 2002)

Canary Island Lizards

16 What is the population of Canary Island lizards?
A. All lizards anywhere in the world that look like the one in the picture.
B. All lizards in the seven islands.
C. All lizards and their preys, nests and territory.
D. All lizards in the same islands that can interbreed.

17 Which is the genetic variation within a population of Canary Island Lizards?
- A. The variation in age among individual lizards.
- B. Injury by fighting for a female, the male lizards look different from each other.
- C. Lizards have different body length.
- D. Depending on the abundance of their prey in each year. there is a fluctuation in an average body weight of the lizards in 1990-2000.

18 Which following statement indicates the fittest lizard in the population?
- A. The lizard that has the biggest brain volume.
- B. The biggest lizard in the population.
- C. The lizard with the longest life span.
- D. The lizard that has the body colour matching with the background so it prevents itself from the predator.

19 How did the lizards adapt to the particular environment in each island?
- A. They don't need to adapt themselves because they always suit with the environment.
- B. They consciously alter a particular organ to fit the environment.
- C. The ones with more suitable traits will increase their number in the succeeding generation.
- D. They gradually strengthen or deteriorate particular organs until it fits the environment.

20 How did the zoologists classify lizard into single group of species?
- A. They put similar lizards into the same species.
- B. They put the lizards that are capable of interbreeding in the same species.
- C. They put the lizards occupying in the same area that eat the same kinds of insects into the same species.
- D. They put the lizards in each island into different species.

Appendix B: Evolution Diagnostic Test (EDT)

Your answers to these questions will assess your understanding of evolution.
Please choose the answers that best describe your own idea about each question.

Heavy Metal Tolerance in Plant

Pollution from industrial sites often has a devastating effect on vegetation near such sites. However, it is observed frequently that after a time certain plants recover and begin to flourish again in polluted areas. An example is provided by the wind-pollinated colonial bentgrass in which a copper-tolerant form has been identified. There is more the copper tolerant form than non-tolerant form in the mine area.

(Adapted from Skelton, 1993)

Fig. 1: Colonial Bentgrass (*Agrostis capillaris*)

1 How did the two forms of Colonial Bentgrass first occur?
- A. There was random mutation within an ancestral generation.
- B. The plant responded to the two environments differently.
- C. A non -tolerant form exists originally and some of it evolved to the tolerant form.
- D. The two forms of bentgrass have always existed.

2 How will a variation in copper-tolerant capacity affect the population in the future?
- A. The individuals with copper-tolerant capacity will be more in the future.
- B. Variation leads to 2 forms of bentgrass, where one is regarded as higher in terms of complexity and functions.
- C. The variation will not effect the population because they are considered to be the same species , *Agrostis capillarie*.
- D. Variation within a plant population does not have any effect on the survival rate.

3 How does Colonial Bentgrass evolve copper-tolerant capacity?
- A. The grass has always had this capacity.
- B. Because individuals with copper tolerance have higher survival and reproduction chances, their proportion will be higher in the next generation.
- C. The ancestry of the grass existed originally in non – tolerant. Some of it changed physiologically to the tolerant form.
- D. The non-tolerant forms gradually accumulated copper-tolerant capacity over generations.

4 There is a difference in the numbers of tolerant and non-tolerant forms of the grass. What determines that difference?
- A. Nature determines the proportion of the two forms constant overtime.
- B. The proportion of the grass is determined by its genetic make up: the form controlled by dominant gene is always more prevalent in a population.
- C. The concentration of copper around the mine induces the non-tolerant form to change itself to the tolerant form.
- D. The concentration of copper around the mine selects one form of grass to survive.

5 Is it possible the two forms of the grass will became two distinct species?
- A. It is not possible for one species to evolve into another.
- B. It is possible if the two forms will have been reproductively isolated and can not interbreed.
- C. The copper-tolerant form is regarded as a new species since it first arose by mutation.
- D. Definitely, the non-tolerant from has a tendency to become more tolerant in order to survive better in the environment.

Melanism in the Peppered Moth

Prior to 1848 the peppered moth occurred in a single from that is speckled grey in colour, but in 1848 a completely back individual was reported from Manchester. This for, called the carbonaria form, rapidly increased in frequency until, by 1900, it formed 95% of population in industrial areas, though it remained rare in most rural areas.

(Quote from Skelton, 1993)

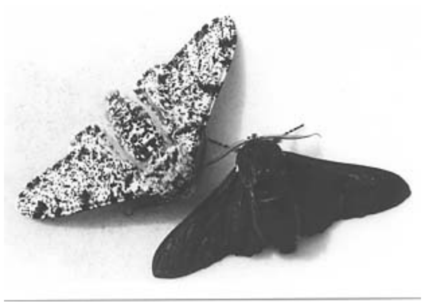


Fig. 2: Peppered Moths in a pale and dark from (*Biston betularia*)

6 How do the peppered moths in a pale and dark from first arise?
- A. Nature gave the two coloured forms to the moths.
- B. The pale moth created by nature responded to industrial area by making its wings darker.
- C. The moth responded to rural and industrial area differently.
- D. The pale moth mutated the new characteristic, dark wing.

7 How will a variation in wing colour affect the moth population in the future?
- A. The variation in wing colour will not have any affect on survival or fertility of the moth in the next generation.
- B. In a particular area, there will be one kind of moth more than the other.
- C. The two forms of moth will not affect the population in the future because they all will still be the same species.
- D. The variation makes one form more complex and functional than the other.

8 How does the pale moth evolve to the dark one?
- A. The pale moth accumulated the black pigment bit by bit over generations.
- B. The pale moth did not evolve to the dark one. The dark wing colour was designed by nature to best suit the industrial environment.
- C. The carbonaria form evolved from the pale one which always exists in nature.
- D. The individual moths with dark wing increase its number over the pale one in an industrial area.

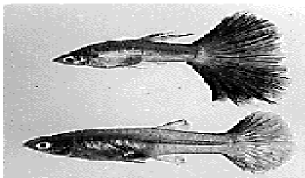
9 Which determine the difference in number of the two forms of moth in a population?
- A. The environmental condition will select only one form of moth to survive.
- B. Depending on its genes, the form with recessive gene is always rare in a population
- C. The environmental condition directs the pale moths to evolve to dark ones.
- D. The numbers of pale and dark in each area are the same over time.

10 Is it possible that the two forms of moth will become the two distinct species?
- A. Yes, it is. All pale moths try to push themselves darker and darker. The darkness is more effective trait.
- B. Yes, it is. The dark from is considered to be a new species since it first occurred by mutation.
- C. Yes, it is. If the two forms are prevent to interbreed for a long time.
- D. No, it is not. It is so hard to become real separated species. If they were, both of them will get worse.

Coloration in guppies

Guppies are small fish found in streams in Venezuela. Male guppies are brightly coloured, with black, red blue and iridescent (reflective) spots. Males cannot be too brightly coloured or they will be seen and consumed by predators, but they are too plain, females will choose other males. Natural selection and sexual selection push in opposite directions. When a guppy population lives in a stream in the absence of predators, the proportion of males that are bright and flashy increases in the population, if a few aggressive predators are added to the same stream, the proportion of brightly coloured males decrease with about five months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar manipulations of natural stream environments (Endler, 1980).

(Quote from Anderson et al., 2002)



Guppies (*Poecilia reticulata*)

11 How did the variety of colour brightness in male guppies first occur?
- A. Nature gave such variety to the guppies for aesthetic purposes.
- B. Guppies gradually adapt their body to diverse environmental conditions.
- C. The original colourless guppies evolved to more colourful forms.
- D. New traits are the result of gene recombination which occurred in their ancestors.

12 How will the variation of colour brightness affect the population of male guppies in the future?
- A. The variation of colour brightness will not affect the fish's survival and reproduction.
- B. It doesn't matter how bright the fish are because, in the future, they will all still considered as the same species.
- C. Variation will make some male guppies more complex and perfect than others.
- D. Depending on an abundance or scarcity of predators, variation in colour brightness will lead one kind of guppy to better survival and reproduction.

13 How did guppies evolve a bright body colour?
- A. Plain guppies accumulated pigments in their cells gradually over generations.
- B. The brightly coloured guppies could better survive and reproduce more offspring than the plain ones, so they increased their proportion in a population.
- C. There is an evolution within a type of guppies. The ancestral colourless fish modified their body to various forms.
- D. The plain guppies did not evolve to be the brighter ones. All guppies originally exists in nature.

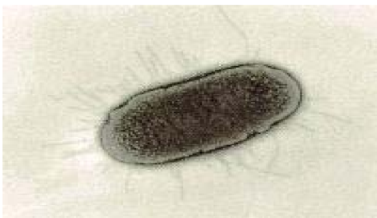
14 There is a difference in the number of each variety within a guppy population. What determines that difference?
A. The proportions of guppies are steady from the past to the present.
B. The abundance of predators in a stream force the plain guppies to change its body colour.
C. Dominant gene make brightly coloured guppies more abundant in the population.
D. The abundance or scarcity of the predators affect the number of each kind of guppy.

15 Is it possible the diverse forms of guppy will became various distinct species?
A. Yes, they can. All plain guppies must evolve themselves to become more complex and colourful.
B. Yes, they can, if all of them are prevented from interbreeding.
C. The brightly coloured guppies are usually considered to be a new species because they came from random mutation.
D. The guppies will not try to push themselves against what nature had already designed.

Biocide Resistance in *E. Coli*

More than 40,000 cases of food-borne infection by the *Escherichia coli* resulting in about 500 deaths occur every year in the United States (Cohen and Tauxe, 1986). These infections result from contact with contaminated beef products, poultry, eggs, or water. In response to consumer concern about unsafe foods and other sources of infection, manufacturers have incorporated biocides or antimicrobial compounds, into an astonishing variety of products, ranging from hand soaps to plastic toys to kitchen cutting soaps. One of the most widely used compounds is triclosan. However, scientists discovered that the bacteria evolve resistance to this compound with surprising rapidity.

(Adapted from Welden and Hossler, 2003)



E. Coli

16 How do the two forms of E. Coli; resistant and non-resistant to biocide, first occur?
A. The bacteria respond to biocide at a different rate.
B. Biocide resistance is the result of random mutation in some bacteria.
C. The variation of biocide resistance came from evolution within a type of ancestral bacteria.
D. The two forms of bacteria were designed by nature. They can both survive well in the environment.

17 How will variation in biocide resistance affect the population in the future?
A. Not at all. Both strains will be the same species, so they can live together peacefully.
B. The variation in biocide resistance has no pressure on how well the bacteria can survive and reproduce.
C. At the appearance of biocide, the resistant bacteria can better survive and reproduce more offspring.
D. There will be two forms of bacteria in the future which only one of them will be more common and complex in its structure.

18 How did non-resistant bacteria evolve biocide resistance ability?

A. The resistant ones increase their number in the following generations because they can better survive and reproduce.

B. The original non-resistant bacteria evolved to another kind of them, biocide-resistant ones.

C. The non-resistant bacteria built up biocide resistant capacity gradually over time.

D. The non-resistant bacteria did not evolve to the resistant form. The two form already exist in nature.

19 There is difference in number of the two forms of bacteria. What determines that difference?

A. The constancy in number between two forms of bacteria is determined by nature.

B. The non-resistant bacteria responded to biocide by accumulating resistance ability overtime.

C. The proportions of the two forms are determined by the forms of gene; dominant or recessive gene.

D. Biocide select which from will survive.

20 Is it possible the two forms of bacteria will became two distinct species?

A. It could not be because if they are, both of them will be worse.

B. It could be, If the interbreeding between the two forms is prevented.

C. The resistant form is considered to be a new species since it occurred by mutation.

D. It must be, the non-resistant form has to become more functional and powerful.

Galapagos Finches

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the island one to five million years ago. Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes, as shown in the figure.

(Adapted from Anderson et al)

Finches

21 How did the different beak types first arise in the Galapagos finches?

A. The variety of beak types exists in the Galapagos since the islands originated.

B. Random genetic change and recombination lead to new variation.

C. Only the primitive beak exists originally. Other deviate forms evolved afterwards.

D. The finches responded to different environmental condition differently.

22 How will the variation of beaks affect the population of finches in the future?

A. Variation of beak type will not affect the finches' survival rate.

B. It is just different physical appearance. It does not have any effects on their growth rate.

C. In the future, the finches with more access to a particular food will increase their proportion in a population.

D. It will not affect the population because they are still the finches.

23 What will cause(influence) a change from one beak type to another?
A. Bit by bit to match the particular food.
B. All various beak types evolved from an original one which existed in the Galapagos long time ago.
C. The finches with a favourable beak will increase its proportions in the population.
D. The finches always have a variety of beak shape and size.

24 What determines the proportion of beak types in the future?
A. Either dominant or recessive gene which controls the expression of beak shape, size and colour.
B. Nature decided that the proportion of each beak type does not change generation to generation.
C. The kinds of food available in each island.
D. The food will induce all finches in an island to change their beak.

25 What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?
A. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
B. All finches are essentially alike and there are not really fourteen different species.
C. Different foods are available on different islands so, individual finches on each island gradually developed the beaks they needed.
D. The was a mutation in the original species of finch.

Appendix C: Current Situation of Teaching Evolution (CSTE)

CSTE is a questionnaire aiming to explore your opinion on existing situation of teaching and learning evolution. The questionnaire consists of two sections; personal data and opinion on the existing situation of teaching evolution. Your response will be used for designing an instructional unit for evolution. By this reason, your honest on the issue is vital. You have 30 minutes to complete this questionnaire.

Section One: Personal Data

Direction: put a tick in an appropriate box

1. Sex ☐ Male ☐ Femal

2. Age ☐ 15-16 years old ☐ 17-18 years old ☐ 19-20 years old

3. GPA …………………….

4. Grading of Biology Subject of last academic year ☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4

5. Do you plan to take biology in the entrance examination? ☐ Yes ☐ No

6. Your favorite ways of learning science (multiple answers are allowed)

   ☐ Listen to the teacher ☐ Hands on ☐ Discussion ☐ Self study

   ☐ Group work ☐ Do a report ☐ Classroom presentation

   ☐ Others……………………………………………………………

7. The science learning resources that you most commonly use

   ☐ School textbook ☐ Teachers ☐ Friends ☐ Tutoring

   ☐ Books ☐ Internet ☐ others……………………………………

8. Topics of evolution that you do not understand (multiple answers allowed)

   ☐ Models of evolution ☐ Process of Natural Selection

   ☐ Hardy Weinberg Laws ☐ Speciation ☐ Macroevolution

Section 2 Existing Situation of Teaching and Learning Evolution

1. Teaching strategies

Direction: Please put a tick in the box that best describe your teacher's teaching strategy/ learning activities on a particular topic of evolution (Multiple answers are allowed for each topic to evolution).

	Teaching strategies or learning activities						
Topics of evolution	Lecturing	Assign to do a report and make presentation	Discussion	Doing an experiment	Doing a project	Self study	Others (please specify)
Models of evolution							
Evidence of evolution							
Population at Equilibrium							
Evolving Population							
Speciation							
Macroevolution							

2. Teaching practice

Direction: Please read the following statements and put a tick in the box that best describe the degree of frequency of that particular event in the classroom of evolution.

Statements	NEVER	SELDOM	SOMETIMES	OFTEN	ALWAYS
1. Your teacher introduced a lesson by making a situation.					
2. Your teacher asked you a number of questions to probe your understanding about a concept before introducing that concept.					
3. Your teacher made a link between your prior idea and the new concept.					
4. Your teacher encouraged you to have a discussion.					
5. Your teacher reviewed all basic knowledge of the new concept before discussing the new concept.					
6. Your teacher asked you to do an activity before making a conclusion about the concept.					
7. Your teacher posed a number of thoughtful questions during a discussion.					
8. Your teacher allowed you to ask any questions about concept.					
9. Your teachers encouraged you to work in group collaboratively					

Statements	NEVER	SELDOM	SOMETIMES	OFTEN	ALWAYS
10. Your teacher linked what you had learnt to the next of topic.					
11. Your teacher referred to conceptual framework.					
12. Your teacher use a model or analogy to illustrate an abstract concept.					
13. Your teacher use the following instructional media in teaching evolution					
13.1 Video player					
13.2 Transpirency					
13.3 Physical model					
13.4 Specimen					
13.5 Others……………………………………					
14. To assess your understanding of evolution, your teacher employed					
14.1 Worksheet					
14.2 Classroom attention and participation					
14.3 Task					
14.4 Testing					
14.5 Others……………………………………..					
15. After the assessment, your teacher gave you feedback and some suggestions					

Any suggestions on teaching and learning evolution

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

Appendix D: An interview schedule to explore existing situation of teaching and learning evolution

Main Questions

1. What Structure of Science of the former curriculum do you currently use to orient biology teaching?
2. In your opinion, what are the good and weak points of that structure?
3. What biology textbook do you use?
4. What do you think about this textbook?
5. What do you think about instructional media and materials suggested by IPST?
6. Do you use any other textbook besides that of IPST? Why?
7. How do you teach the topics of models of evolution, natural selection and speciation? What teaching strategies do you employ?
8. How did your students response to that strategies?
9. How do you assess student understanding of evolution?
10. What is the most difficult topic of evolution to students? Why?
11. What are your difficulties in teaching evolution?
12. What you do think you need to improve teaching evolution?
13. How do you prepare for teaching evolution under the school based curriculum that will be implemented next year?

BIOGRAPHICAL DATA

Name:	Mr. Pongprapan PONGSOPHON
Date of Birth:	December 17, 1979
Place of Birth:	Saraburi, Thailand
Graduation:	B.Ed. (First class hons) in General Science and Biology, Chulalongkorn University Ph.D. (Science Education), Kasetsart University
Rewards:	International scholarship awards from The National Association for Research in Science Teaching (NARST) conference 2006 during April 3-6, 2006 at San Francisco, California, USA.
Scholarships:	The scholarship to pursue a doctoral study at Kasetsart University under the Project for the Production of Science and Mathematics Talented Teachers (PSMT) which conducted jointly by the Royal Thai Government Agencies and the Institute for the Promotion of Teaching Science and Technology (IPST).