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TEACHING EVOLUTION WITH PALENTOLOGICAL DATA: A WEB RESOURCE FOR PROFESSIONAL EDUCATORS

A Thesis Presented

by

Corey Coutu

to

The Faculty of the Graduate College

of

The University of Vermont

In Partial Fulfillment of the Requirements
for the Degree of Masters of Science
Specializing in Geology

February, 2008

Accepted by the Faculty of the Graduate College, The University of Vermont, in partial fulfillment of the requirements for the degree of Master of Science, specializing in Geology.

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ABSTRACT

Over the past thirty years, the presence of naïve notions, or alternate conceptions in a student population, have been consistently identified as playing a key role in the inability for students to understanding evolutionary theory (Brumby, 1979; Greene, 1990; Settlage, 1994; Ferrari and Chi, 1998).

Ferrari and Chi (1998) document that most naïve notions associated with evolution education can be linked to mistaken ontological categorizations, where students associated evolutionary concepts with event process (where organisms determine implicitly or explicitly their destiny) instead of equilibration processes (ongoing, non-distinct actions) to which they belong. Research in the remediation of naïve knowledge (Ferrari and Chi, 1998; Bishop and Anderson, 1990) suggest the best way to overcome these "naïve notions" is by utilizing curriculum that (a) assess students misunderstandings, (b) present students with situations that cause them to contrast these misconceptions with current scientific theory, and to (c) gives students the opportunity to reflect on what they have learned, and explore this new information through guided learning activities.

Based on this research, a teaching methodology that incorporated constructivist pedagogy with inquiry based methods, and framed the study of evolution within palentological context was tested on a classroom of college freshman during the spring of 2006. This approach was found to successfully identify and remove naïve conceptions from student understanding. Based on these results, this methodology was turned in to a distance-learning tool, consisting of a web based teaching module designed around fossil data from a subset of Kelley's (1989) study of the molluscan fauna of the Chesapeake Group.

The module mimics the classroom experience by replacing the teaching with interactive web pages, photographs, and video media detailing the processes utilized by the scientific community to identify, quantify, and interpret morphologic variation. Web module content is focused on the examination of gradual morphological change documented in two fauna of mollusks, and presented in a cross-disciplinary approach (geology, biology, and statistics) that expands the bounds of traditional science curriculum by bridging the gap between scientific research and science education. In a pilot study conducted to determine the ability for this module to be utilized in a science classroom, naïve notions were reduced by 10% when students utilized web material to examine evolutionary change. These results indicate that while effective at adding to the ability for educators to reduce student's naïve understandings, the module is not effective at replacing traditional classroom instruction. The website can be found on the University of Vermont's Perkins Museum of Geology homepage (http://www.uvm.edu/perkins/index.html), where visitors are asked to complete a survey in exchange for content use. The survey is part of an ongoing longitudinal study, the results of which will be quantified and used to improve and expand web content.

CITATION

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Chapter 1: Theoretical Background

When teaching evolution, the identification and remediation of naïve knowledge is paramount, due to the degree to which these "misconceptions" inhibit the process of learning. Understanding the conceptual background behind naïve knowledge is paramount in this pursuit, because it is through understanding how naïve knowledge is characterized and understood can one then design a curriculum to identify and remediate the notions in the classroom.

Introduction

The presence of naïve knowledge in students' conceptual understandings of evolutionary theory was first documented by Dobzhansky (1973), and continues to be identified as the predominate construct affecting a students' ability to internalize formal evolutionary concepts (Chi and Roscoe, 2002). With "high stakes" state and federal educational standards requiring students to meet K-12 science curriculum standards that emphasize the role of evolution and natural selection in the study of science, the inability to identify and remediate naïve notions in the classroom have become imperative.

The process by which naïve knowledge inhibits formal learning has prompted an examination into the ways in which evolution is presented in science classrooms. In secondary settings, new knowledge is often obtained via textbooks, prompting a study by Linhart (1997) to examine how textbooks present evolutionary theory across numerous disciplines. Linhart examined over 50 major textbooks in the fields of biology, evolution, ecology, genetics, paleontology, and systematics for their evolutionary content, and found that the texts provided a very reasonable explanation of evolution within a specific

discipline, but failed to convey the interdisciplinary studies that have been used to examine evolutionary change over the past 200 years.

For decades, scholars have studied the dynamics of evolution and evolutionary theory; however, only recently have these studies been aimed at determining how evolution is misunderstood by the public. Research at colleges and universities across the country has consistently documented persistent shortfalls in student comprehension and retention of fundamental Darwinian concepts (Rudolph and Stewart, 1998). General surveys of evolutionary understanding across college curriculum document that current college students have a "woefully lacking" understanding of elementary evolutionary concepts (Bishop and Anderson, 1990). This surprising conclusion came about as a bi-product of a study conducted in order to determine the level of understanding retained in introductory college biology classrooms. Student understanding was assessed before and after a semester-long biology class, and although the students had taken (on average) 1.9 years of previous biology courses, performance on the pre-test and post-test was uniformly low (Bishop and Anderson, 1990). This finding stunned researchers by suggesting that not only did students not understand fundamental concepts of Darwinian evolutionary theory in high school, but they were also failing to grasp this understanding after a semester-long course in college level biology. In a critical review of their methods and curriculum design, Bishop and Anderson (1990) were able to document that students' previous misconceptions appear to account for most of the inability to learn or retain concepts presented in a college level biology classroom. These findings seem to mimic

those published by Brumby (1979) and Green (1990), which document that misconceptions serve as intellectual "roadblocks" on the path to learning.

The role of misconception in evolution education

When students' pre-conceived notions (misconceptions) conflict with information presented in a formal setting, they are labeled as naïve knowledge (Ferrari and Chi, 1998). Naïve knowledge is identified as a student's pre-existing incorrect information, commonly associated with impeding the acquisition of formal knowledge (Chi and Roscoe, 2002). According to these authors, naïve knowledge is commonly divided in two sub-categories; pre-conceptions, or knowledge that can be readily revised or removed via verbal or written instruction, or misconceptions, knowledge that is highly resistant to change even in the face of guided instruction. The ability of individuals to correctly learn and discuss the process of Darwinian evolution is often impeded by such misconceptions (Dobzhansky, 1973; Brumby, 1979, 1984; Engel-Clough & Wood-Robinson, 1985; Jimenez & Fernandez, 1987; Bishop and Anderson, 1990; Ferrari and Chi, 1998).

Research by Ferrari and Chi (1998) suggests these misconceptions stem from mistaken ontological categorization, a process used to store information in the brain that occurs when students assign concepts to an ontological category that it does not belong. Ontological categories are mental constructs used to represent and store concepts and events that share a common relationship (Gruber, 2007).

Ontological classifications

In cognitive psychology, an ontological category is defined as a conceptual structure consisting of a set of objects that people believe in together (Chi, 1997). When

people believe that a certain set of objects belong to a pre-defined category, they can easily incorporate new instances of the category in to their pre-existing mental model. This grouping allows people to assign the same label to a new instance of the category and make inductive and deductive inferences to new category members (Chi, Hutchinson, & Robin, 1989). The cognitive advantage to having categories is the ability to code new experiences or information as an instance of a familiar category, thus reducing the demand on the perceptual, categorizing, and reasoning processes of the mind.

Evolution is a process, thus ontologically categorized as a "process concept," one of the three faceted taxonomies to which all concepts belong (Chi, 1997). Process concepts are delineated in to two sub-divisions, event and equilibration processes; with event processes associated with distinct, sequential, goal orientated actions, and equilibration processes associated with ongoing, non-distinct, uniform actions. Ferrari and Chi (1998) hypothesize that failure to internalize the concept of Darwinian evolution is not due to an inability to understand distinct Darwinian principles: rather an inability to correctly categorize evolution as an "equilibration" ontological event.

Human predisposition: Event and equilibration processes

Results from Ferrari and Chi (1998) demonstrated a correlation between "event" ontological attributes and non-Darwinian (Lamarckian) explanations, as well as a correlation between "equilibration" attributes and a distinct understanding of formal evolutionary concepts. When students give non-Darwinian explanations, they tend to give primarily a Lamarckian account, in which organisms determine (implicitly or explicitly) what features they need to adapt, develop these features, and pass them on to their

offspring in the form of altered heredity, thus gradually transforming the species over time. Lamarckian notions are prevalent and are consistent with a casual, intentional, event like process. This latter Lamarckian notion may seem more intuitive perhaps because humans have a predisposition to perceive all processes are events, and to tell interpretive stories in which agents act to overcome obstacles in the pursuit of goals (Bruner, 1990). Such a predisposition would explain why it is so difficult to overcome our initial misconceptions.

While many students responded with phrases that can be considered Darwinian (because they refer to one or more Darwinian principles), the overall framework to which the explanation is imbedded is still incorrect, and contains casual and or intentional types of reasoning. This intermittent understanding of individual Darwinian principles leave students with the illusion of having understood Darwinism when in fact they still harbor essential misconceptions about the Darwinian mechanism for explaining change. The misapplication of Darwinian principles (organisms change over time), to non-Darwinian understandings (these changes come about due to need or desire) is disastrous for learning evolution in the classroom, as it introduces naïve understandings, that once engrained, acts to and inhibit the acquisition of formal knowledge on evolutionary processes.

Overcoming misconceptions

Outlined in *Science Teaching Reconsidered: A Handbook*, the best method for removing naïve knowledge in the classroom involves a three step treatment that seeks to, identify students' misconceptions, provide a forum for students to confront their

misconceptions, and help students reconstruct and internalize their knowledge, based on scientific models (Committee on Undergraduate Science Education, 1997).

I hypothesize that a curriculum that presents evolution as an equilibration process, and utilizes the Committee on Undergraduate Science Education model to identify and correct naïve notions, should improve students understanding of evolutionary theory. In this curriculum the integration of conceptual change theory, will manifest itself through experiential learning activities and inquiry-based approaches. I believe that using inquiry methods to examine and quantify evolution in a group of fossilized organisms will provide a tactile experience and a powerful tool by which to study evolutionary change over time.

To gauge effectiveness of this approach, curriculum was designed and tested in the spring of 2006 on the GEOL 062 classroom that examined evolutionary change through the study of Earth's history. This curriculum was based the Committee on Undergraduate Science Education model, by identifying naïve conceptions, presenting the results of this survey to students via a classroom discussion, and helping students to internalize "formal" understandings through lecture and laboratory activities.

Chapter 2: Identifying and Correcting Misconceptions: The GEOL 062 Classroom Experience

Introduction:

In the spring of 2006, a pilot curricular program was launched in GEOL 062 (Earth and Environments Through Time) that utilized the latest theoretical research to design a three-step approach to identify and remediate naïve notions concerning evolutionary theory. This curricular revision was prompted by previous research on naïve notions in the classroom which documented that approximately 53% of information held by College students (Bishop and Anderson, 1990), and 57% of information held by High School (Settlage, 1994), concerning evolution or evolutionary theory is considered naïve, or incorrect. It was hypothesized that the identification of, and introduction to, naive knowledge through guided instruction, would result in a decrease in naïve understandings in the classroom.

Constructivist learning theory states that curriculum best studied to remediate a student's naïve knowledge should include activities that help students to identify their misconceptions, while supplying them with learning activities that act to remediate misunderstanding through guided instruction. Assessment of previous years of Geol 062 students identified persistent misconceptions in this population, making it an ideal case study.

Classroom Misconceptions: GEOL 062

Geol 062 is an introductory level geology course, designed to integrate the study of how the Earth, atmosphere, and biosphere have changed over time. The last third of

the semester is traditionally devoted to a review of Darwinian evolution, by examining natural selection and evolutionary change using examples from the fossil record. In the 2004-2005 year the classroom population consisted of 12 students (Freshman-Senior) each with a background in science, but no formal training in evolutionary study. The procedure utilized to examine naive notions in this setting consisted of several steps: (1) to identify misconceptions in the student population via a knowledge survey, (2) to introduce students to their misconceptions through a series of formal classroom lectures, and (3) to remediate misconceptions via guided instruction, specifically the manipulation of fossil data.

The Knowledge Survey

The knowledge survey is a pedagogical tool that is utilized before the onset of instruction, and has been found particularly useful in the identifying naïve knowledge associated with evolutionary theory (Bishop and Anderson, 1990). The ability to identify misconceptions reflects the true power of the knowledge survey, as it provides a means for educators to introduce students to their own naïve understandings. This process has been documented to successfully remediate naïve notions via conceptual change, by causing students to shift their naïve conceptual understanding of evolutionary change to an alternatively distinct ontological category (Chi and Roscoe, 2002).

The knowledge survey utilized in this investigation was adapted from a tool created by Bishop and Anderson (1990) that identified naïve knowledge in college student populations. The survey utilized in the Geol 062 classroom consisted of six short answer questions (Appendix A), the responses to which were cross referenced against 20

flagged keywords that were used to quantify misconception via word choice. Keywords were grouped into three categories, evolutionary keywords (those associated with evolutionary processes), teleological keywords (those associated with evolution occurring due to a purpose, direction, or designed action), and Lamarckian keywords (those associated with transmission of phenotypic traits from ancestor to decent). Of these three groups, only evolutionary keywords were associated with a correct understanding of how the process of evolution operates, uses of teleological or Lamarckian keywords were associated with naïve understandings or misconceptions. In order to produce non-biased results, student responses and keyword tally sheets were distributed to two individual parties for assessment.

Results from the knowledge survey indicated that student responses were dominated by misconceptions, especially the teleological and Lamarckian keywords, "need", "use", and "learned" (Figure 2.1). After the knowledge survey had been tallied, 121 keywords were identified, with 43% of keywords reflecting teleological or Lamarckian concepts (misconceptions), and 56% of the responses reflecting evolutionary concepts (Table 2.1). The use of teleological and Lamarckian concepts in student responses was used to indicate misconception in the student's ability to accurate understanding evolutionary theory. The percentage of evolutionary concepts found to be naïve in this study (43%) reflect a similar level of naïve information as Bishop and Anderson's (1990) work on college populations (53%). Sadly, this similarity in results indicates that in the 17 years since Bishop and Anderson's study was conducted not much

appears to have changed in the percentage of naïve notions concerning evolutionary theory contracted by college student populations.

Informing Students of their Misconceptions

Primed with the information gathered from the knowledge survey on the existing misconceptions in the student population, the results of this survey were then presented to the class via a formal classroom lecture. This lecture was designed to present the survey data to the class, and present anonymous examples of student responses to specific questions. Responses were read aloud, and then discussed in the classroom. Following this activity, lectures were presented to the students detailing Teleological / Lamarckian views on evolution, why they are incorrect, as well as on how true Darwinian evolution operates. These lectures focused on the concepts of populations and genetic variation, with these concepts consisting of the cornerstone of evolutionary theory, and providing the raw material necessary for evolutionary change.

Changing Misconceptions via Guided Instruction

In order to enforce the concepts of populations and genetic variation, the class was assigned a morphometric data lab that consisted of collecting and manipulating shell data from Spiriferid brachiopods. The lab was designed to allow students to (1) allow students to collect and analyze quantitative data on fossil morphology, (2) to use this data to recognize populations and the morphologic variation between them, and finally (3) to examine morphologic change as a function of time. The lab was carried out by collecting measurements of features on fossil shells (number of ribs, width, length) from both groups of organisms, and then plotting that data in excel against stratigraphic height.

From the graphs students were asked if based on these measurements and graphic analysis, were the two groups of fossils one population or two. A follow up question was also presented, which asked, if the two groups represented two populations of organisms then how is one able to recognize distinct populations.

During the activity, the ability to personally retrieve shell data was identified by the students as engaging and well received. At the end of the lab period not only had most individuals learned that the ability to discern populations was based on genetic variation, but also the keyword usage in their writing, and discussions, began to reflect a more Darwinian understanding of evolutionary change.

Summative Assessment

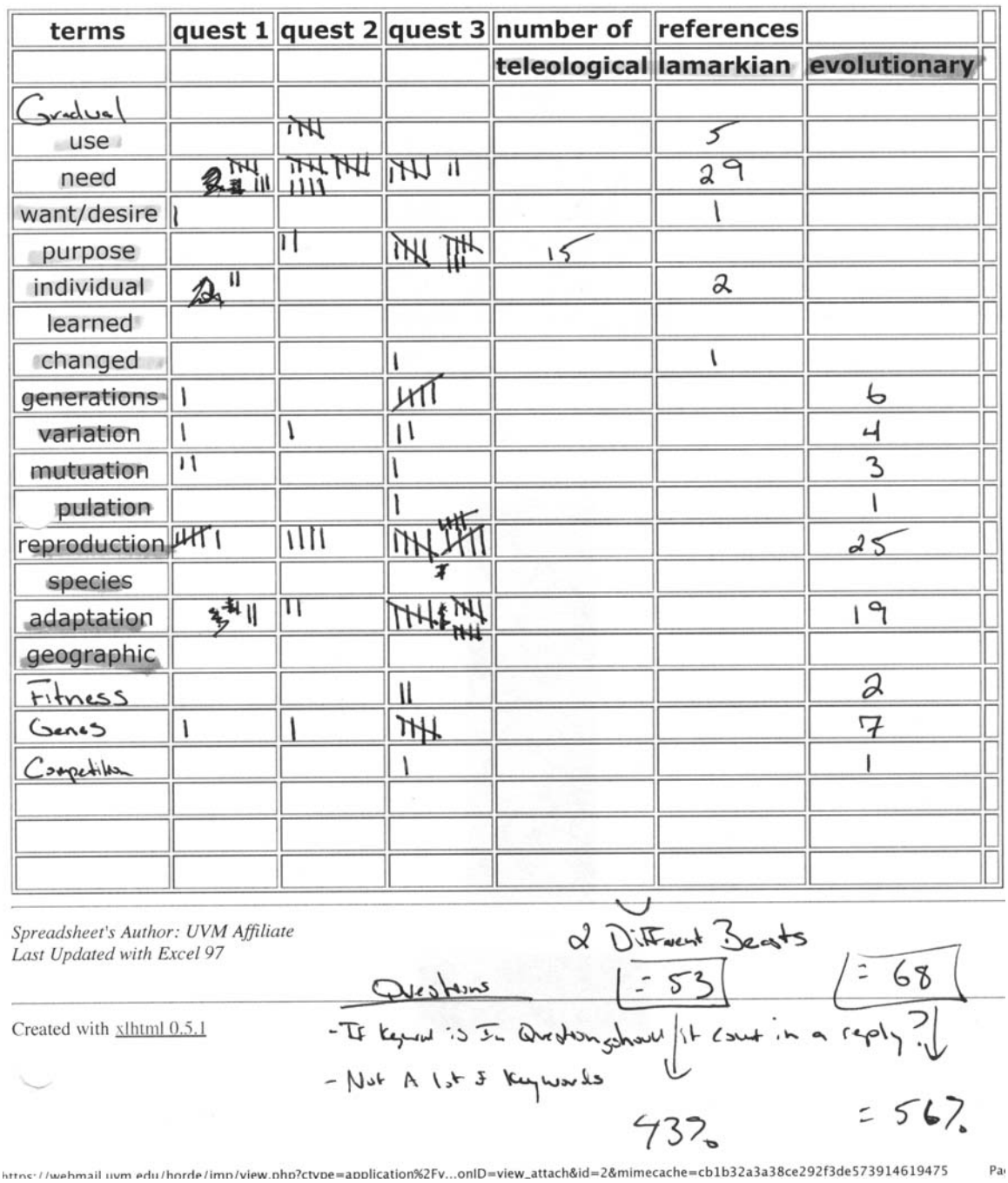
In order to test the effectiveness of the approach a summative assessment was administered and used to quantify the level of misconceptions found to have remained naïve after instruction. Because this pilot program was incorporated in to the curriculum of a classroom in session during the spring of 2006, the summative assessment utilized to collect this data were included in the GEOL 062 final exam. This exam consisted of 16 questions, the answers to four of which were examined misconceptions via a key word tally. The results from this tally produced unexpected results, when absolutely no teleological or Lamarckian keywords used to answer any of the final exam questions. These results indicate that the four-step approach at correcting naïve notions proved effective in the student population sampled.

Conclusion

While determining that the four-step approach enacted in Geol 062 was effective, this investigation also identified that current levels of misconception in science classrooms is still around 43%, a figure that close to levels determined in 1990 by Bishop and Anderson (53%). This data indicates that even with all the work that is currently being done to teach evolution, there appears to still be a fundamental problem to the way that students interpret the process of Darwinian evolution. In the Geol 062 classroom, it was observed that the fossil record and geologic time were great strategies for reducing the amount of naïve knowledge persistent in student, especially after the classroom discussion and manipulation of shell data. This observation led to two hypotheses (1) that having students learn about their naïve notions can guide subsequent instruction, and (2) the collection and manipulation of fossil data may be a strategy that could be utilized on other classrooms to remediate similar misconceptions on evolutionary change over time. While the fossil record has been often cited as adding "proof" to those who disagree that evolution occurs, citing incorrectly that no examples of gradual change over time occur, in Geol 062 students were able to collect data from real fossil and use that data to examine evolutionary change. Based on the effectiveness of manipulating real fossil data, and utilizing the four-step approach tested in the Geol 062 classroom, it was decided to build a distance-learning tool, modeled after the classroom experience might be an effective means of providing teachers with similar methods and data to utilize in their classrooms. Chapters 4 and 5 describe the testing and evaluation of these hypotheses.

Table 2.1 Tally of flagged keyword usage (GEOL 062)

Keywords	Documented Use
Evolutionary	
Generation	6
Variation	4
Mutation	3
Population	1
Reproduction	25
Species	0
Adaptation	19
Fitness	2
Genes	7
Competition	1
Teleological	
Want	1
Desire	1
Need	29
Individual	2
Purpose	15
Lamarckian	
Use	5
Learned	0
Changed	1



terms	quest 1	quest 2	quest 3	number of	references	
				teleological	lamarkian	evolutionary
Gradual						
use					5	
need					29	
want/desire	1				1	
purpose				15		
individual					2	
learned						
changed			1		1	
generations	1					6
variation	1	1				4
mutuation			1			3
pulation			1			1
reproduction						25
species						
adaptation						19
geographic						
Fitness						2
Genes	1	1				7
Competition			1			1

Spreadsheet's Author: UVM Affiliate
Last Updated with Excel 97

Created with xlhtml 0.5.1

2 Different Beats

= 53

= 68

Questions

- If keyword is in Question should it count in a reply?
- Not A lot of keywords

43%

= 57%

https://webmail.uvm.edu/horde/imp/view.php?ctype=application%2Fv...onID=view_attach&id=2&mimecache=cb1b32a3a38ce292f3de573914619475 Pa

Figure 2.1 Tally Sheet utilized in quantifying evolutionary / non-evolutionary keywords in students responses

CHAPTER 3: Paper for submission to *Journal of Geoscience Education*

TEACHING EVOLUTION WITH PALENTOLOGICAL DATA: A WEB RESOURCE FOR PROFESSIONAL EDUCATORS

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Abstract:

Research suggests that new concepts cannot be learned by students, if alternate (naïve) models to explain the phenomenon already exist (Chi and Roscoe, 2002). In classroom settings, similar misconceptions concerning evolutionary theory were corrected by facilitating the identification, confrontation, and remediation of naïve knowledge through inquiry based projects, classroom lectures, and laboratory activities. Based on this classroom model, a series of web modules have been created that mimic this approach by providing students with an independent and autonomous way to confront and remediate naïve knowledge through the examination and manipulation of a fossil data.

Designed to bridge the gap between scientific research and science education, the teaching module, Evolution 101, examines gradual phyletic change as recorded in the fossil record (Kelley, 1989). Module content include photographs and videos that detail the processes used to quantify and interpret morphologic variation, as well as the geologic background necessary to interpret palentological data. This module is located on the University of Vermont's Perkins Museum of Geology homepage (http://www.uvm.edu/perkins/index.html), where visitors are asked to complete a survey in exchange for content use. Current trials have identified the ability for module content to reduce classroom misconception by 10% when utilized in classroom curriculum.

Introduction

The existence of alternate, or naïve, models to explain natural phenomenon have been documented to inhibit a learners ability to acquire new or formal explanations of scientific processes (Chi and Roscoe, 2002). Curriculum specific activities can be utilized to limit the effects of these naïve notions on classroom learning by providing students with the ability to identify these misconceptions, creating a forum for students to confront their misconceptions, and by designing guided learning activities that challenge students to reconstruct and internalize their knowledge via on scientific models (Committee on Undergraduate Science Education, 1997).

This model was utilized to remediate 100% of the identified naïve knowledge in GEOL 062 by identifying student misconceptions with a knowledge survey, informing the students of their misconception, and corrected these misconceptions through a series of lectures and laboratory activities examining evolution in the fossil record. The success of this approach yielded valuable insight on curricular methods that could be successfully utilized to remediate naïve knowledge in a student population, thus was applied to the creation of a web based teaching module.

Content Design and Data Selection

The GEOL 062 classroom provided evidence that with the correct background in geology and earth history, the collection and manipulation of fossil data provided the conceptual background necessary for students to reconstruct and internalize "new" knowledge on how evolution operates. Web content was developed to mimic this approach, but also modified to fit the needs of teachers and students who may lack a

conceptual background in evolutionary theory or historical geology to correctly identify or interpret fossil data.

The first step in recreating the classroom experience was to identify published palentological data that could be used the guide module content by examining evolutionary change over time. Data on recognizable fossilized organisms that could be examined with "basic" statistical methods were targeted, but were challenge to identify. Initially content was focused on data by Ward and Blackwelder (1975), on a genus of mollusks known as Chesapecten, however initial statistical regressions on the data revealed low correlation coefficients (0.14), values supported by independent research by Kelley (1983). Further research on work by Kelley (1989) indentified an acceptable set that examined the evolutionary trends within bivalve prey of Chesapeake Group's *Naticid* gastropods. The data presented in Kelley's (1989) paper met the criteria for module design by utilizing identifiable fossils (clam shells) that clearly presented the gradual evolutionary change as results of an identified stress on the population (predation). The choice was strengthened by the morphometric techniques utilized by Kelley in the quantification of shell features (shell length, width, height, internal volume). Such features were not only easily to identify and replicate, but could also be adapted and demonstrated for classroom use.

Once a data set had been identified, module content was created collaboratively consisting of input from pre-service and professional educators. Administered in the spring of 2006, a short survey was sent out to high school teachers in northwestern Vermont, as well as a group of pre service educators with in the University of Vermont's

college of Education and Social Service. This survey was administered to gauge what need, if any, a web based teaching module that presented quantifiable shell data to examine evolutionary change could offer to this group of education professionals. Survey results (Table 3.1) indicate a need for content that focuses on background information on the basic tenants of evolution, basic geology and Earth history, and a data set documenting evolution in a group of fossilized organisms. To address this need, a learning module was created that presented users with the geologic content and data necessary to facilitate the examination of evolutionary change with in the fossil record.

The Website and Teaching Module:

The website (http://www.uvm.edu/perkins/evolution/) is designed to provide high school educators with real data from the fossil record for classroom use. The website provides cross-diciplinary materials (biology, geology) that supplement existing web-based material. The homepage is broken up in to four sections (Figure 3.1), *Evolution 101*, containing supplemental background on the theory of evolution, *Virtual Field Study*, the web site core, hosting potions of data obtained from published work (Kelley, 1989), *Resource Center*, filled with links to commonly asked questions, evolution news, and classroom activities, and *Published Data Sets*, a place where educators can download data sets and tutorials for classroom use. Each of these four sections is further described in detail below.

Evolution 101

The Evolution 101 module was designed as a resource for educators to strengthen their contextual understanding of evolutionary theory, how it operates, and how it can be

examined in the fossil record (Figure 3.2). This learning module breaks down the theory of natural selection in to five sections, the first consisting of a brief history of evolutionary theory beginning in 1666 when naturalists first recognized that animal forms can be preserved in rock through time, and extending through the work of Lyell and Darwin. This approach sets the foundation of evolutionary theory not set in biology, but instead in stone, where the fossil record resides. After setting the context of current evolutionary theory, this section of the website discusses they theory of evolution via the mechanisms of natural section, detailing how natural selection operates, and how it can be used to study the evolution of organisms in the geologic past. This section concludes with a discussion of how palentological research on evolution is carried out, outlining the various modes by which evolution occurs (Phyletic Gradualism and Punctuated Equilibrium), and introducing the application of these models to the research done by Kelley (1998) which are presented in the teaching module portion of the website.

Field Study: Chesapeake Bay

The virtual field study of the Miocene-Pliocene exposures on the western shoreline of Chesapeake Bay is the core of the website (Figure 3.3). In the experience of a "field trip", users experience the process used by geologist's to approach the study of evolutionary change. Acknowledging the limitations of some science classrooms, the virtual field trip provides users with the ability to virtually see a fossil "in the wild", while examining how evolution is examined in a geologic context. Module components include mpegs and photographs that used as visual aids, and designed to provide users with an interactive way to identify rocks and fossils, describe rocks in the field, and

observe the collection and quantification of shell data. Modeled after the scientific method, the field trip seeks to engage users in the processes of discovery, as they manipulate data and examine evolutionary change.

Published Data:

The published data section (Figure 3.4) is an extension of the Virtual Field Study teaching module, where users are provided with published palentological data that can be used to examine evolutionary change. This data is posted and free to access to anyone, wheither you are an educator looking for fossil data for general classroom use, or a student using a tutorial to examine Kelley's (1989) data on your own. Besides offering published data for manipulation, this section of the teaching module provides links to information on scientist currently researching evolution in the fossil record, as well as access to the manuscripts from which they were extracted.

Resource Center:

The resource center (Figure 3.5) was designed to provide supplemental information to educators seeking background knowledge about geology, lesson plans, or other evolution education opportunities. Several external links are included in this section of the web module, and include frequently asked evolutionary questions on evolutionary theory (http://www.pbs.org/wgbh/evolution/ library/faq/cat01.html), the paleomap project by Christopher Scotese (www.scotese.com), that documents plate and climate reconstructions throughout Earth history, and "evolution in the news" (http://evolution.berkeley.edu/evolibrary/news/newsarchive_01), a collection of continually updated news stories on evolution, or evolutionary theory archived on the

Berkeley Museum of Paleontology website. Designed content in the resource center includes two mini-modules that examine fossilization, and how geologists examine evolution over "geologic" time. These mini-modules were created to help non earth science teachers understand some of the geologic principles that underline the virtual field trip and the fossil data sets. This content is supplemented with a variety of text and photographs, many including lesson plans, that emphasis the connection between the study of geology and biological evolution. Besides these mini-modules, this section is also characterized by a large collection of classroom activities, which include over a dozen external resources on evolution, evolution education, and other learning opportunities.

Assessment and Development

In order to study the impact of this website and its value in promoting the inclusion of fossil data in teaching evolution we utilized several methods of assessment. The first was a tool adapted from Schrock (1995), that was used to assess mechanical attributes of the website including design, content layout, accessibility, and clarity. The sample group for the assessment (n=10) consisted of geology faculty, undergraduates, and graduate students. The feedback from this assessment was used to modify website layout and accessibility, and was helpful in providing insight on the presentation and scope of the material presented.

Following the mechanical assessment, a content assessment was distributed to secondary and pre-service science educators in Northwestern Vermont (n=12). This assessment asked teachers to express their ideas on the usability of a teaching tool that

provided teachers will palentological data, and outside resources that would facilitate teaching evolution in their classrooms. The results of this survey (Table 3.1) are to be integrated in to the teaching module in an effort to create a tool that appeals to a large group of science educators.

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Table 3.1 Survey administered to Pre service (8) and Professional Educators (4) 2007

Short Answer Survey **N=8**

	Yes	No	Comments
1) Have you ever considered using fossil based evidence as a method of teaching evolution?	10	2	Pre-service teachers repeatedly express concern over a lack of fossils, and fossil data (local examples) to use in classrooms
2) Would you be interested in a resource that provided the opportunity to examine evolution via collected and published palentological data?	12	0	Pre-service teachers express the need for published and accessible data sets and tutorials, Want to be shown how the data was collected and how it can be utilized in the classroom
3) Would you be interested in an online resource that connects published literature and research methods with interactive field trips that detail how collected data is quantified and evaluated via a range of media?	18	0	Pre-service teachers express the need for an easy to use resource, with background geology and hands on and interactive activities. Believe resource should include assessment tools, activities, and curricular ideas that could be adapted or modified to fit the needs of individual teachers

Table 3.2 The five common misconceptions and their sources, identified by Greene (1990)

Prevalent Misconception:	Source:
• *Misconceptions from experience*:	Obtained from everyday experiences
• *Self –constructed misconceptions*:	Obtained when students see or hear information that conflicts with what they already know, throwing their understanding in to a state of disequilibrium
• *Taught-and-learned misconceptions*:	Obtained from unscientific facts taught informally by parents or others
• *Vernacular misconceptions*:	Obtained when common words take on a different meaning in a scientific context
• *Religious based misconceptions:*	Obtained from concepts in religious teachings that, when applied to science education, become factually inaccurate

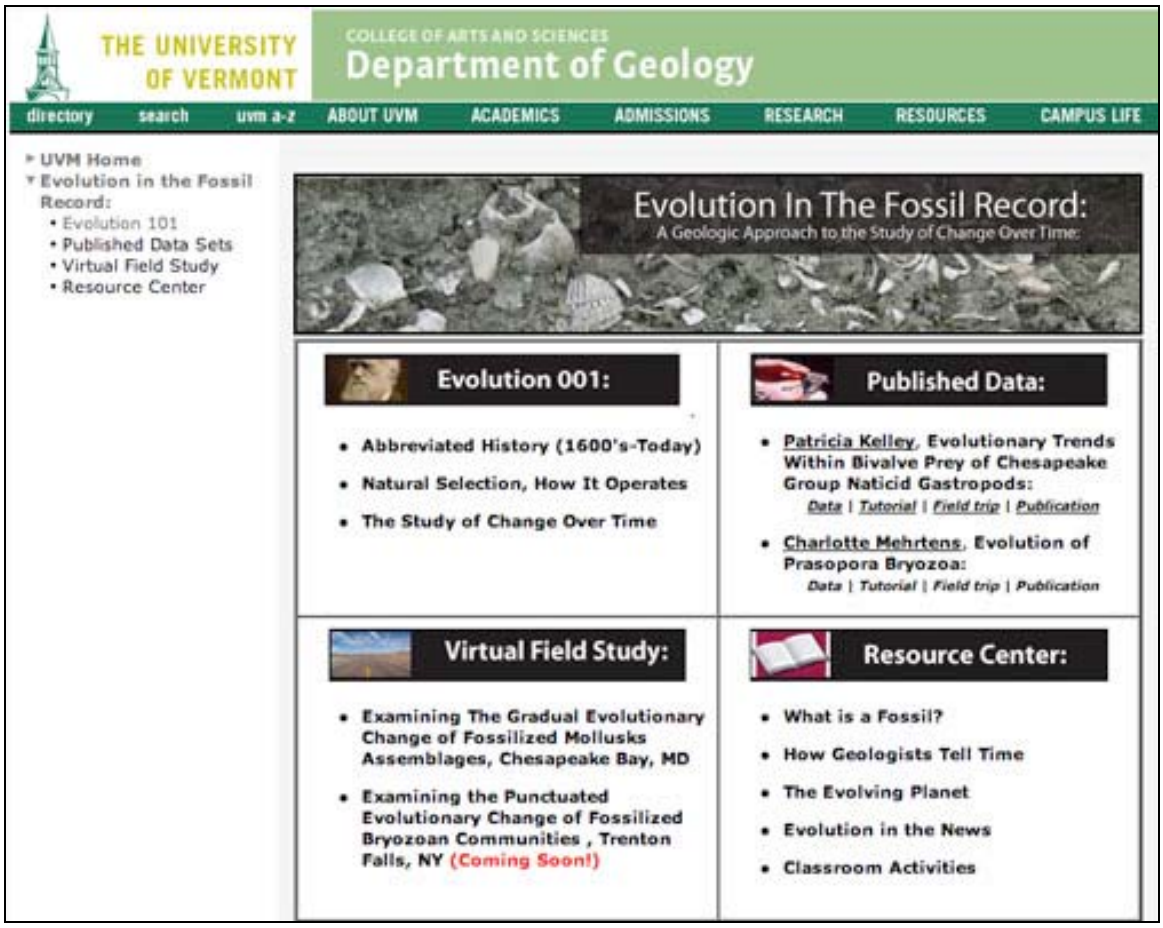

Figure 3.1 Evolution in the Fossil Record home page. Web site design based in the UVM webpage template, and created in conjunction with the UVM web publishing team. Navigation options and page size coincide with the UVM template, however page layout and design is modeled after guidelines put forth by Berger (1998), and Hammerich (2002), which suggested that each page have text limited to one or two paragraphs, a set navigational bar, and colored heading.

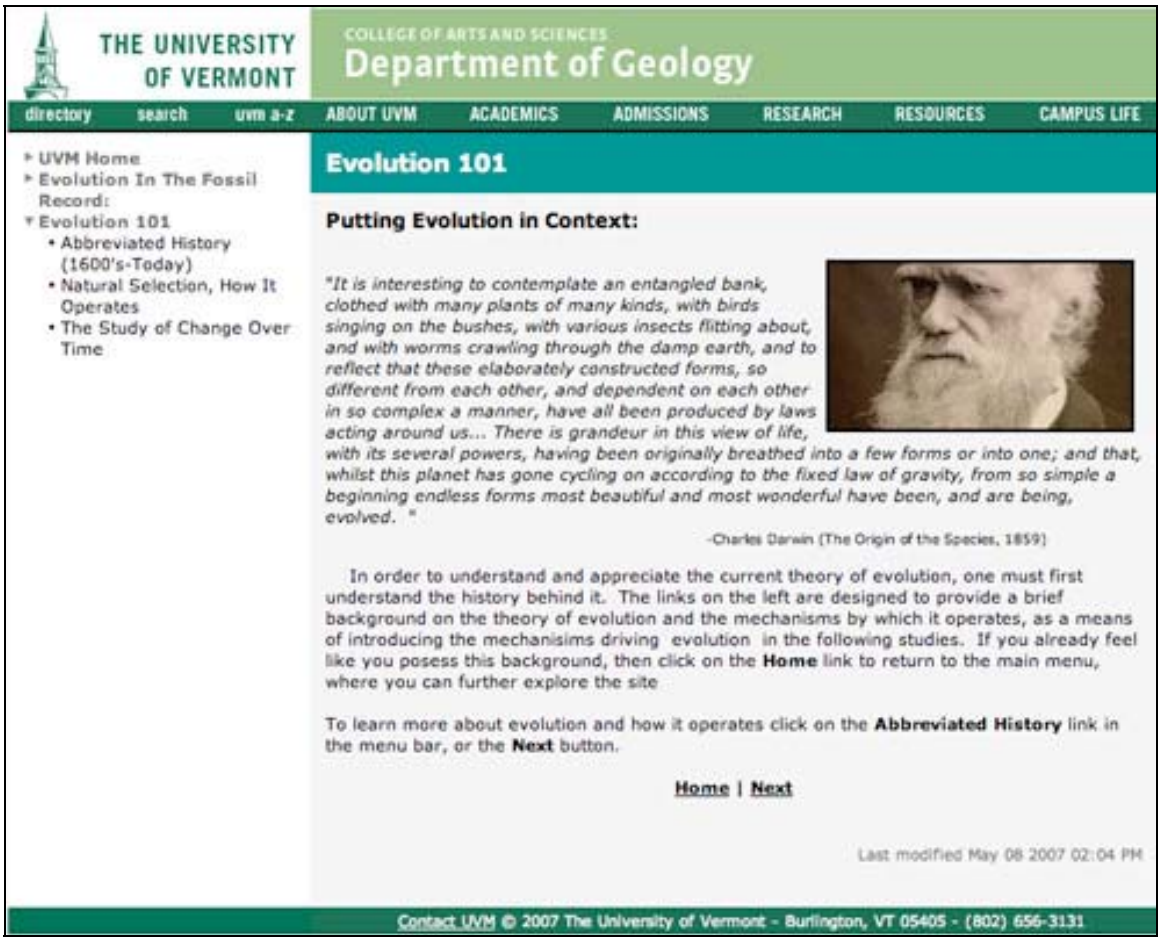

Figure 3.2 Evolution 101 Module home page

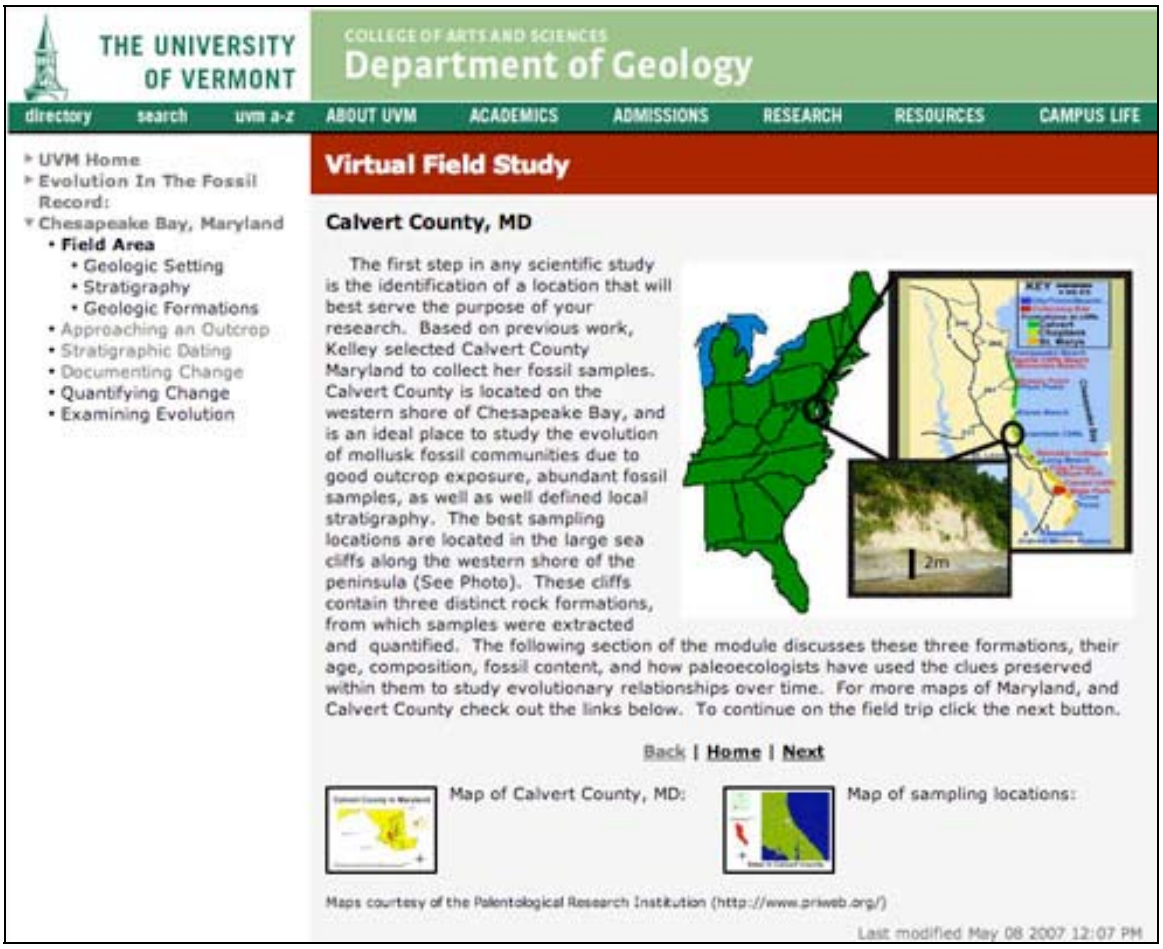

Figure 3.3 Virtual Field Trip home page

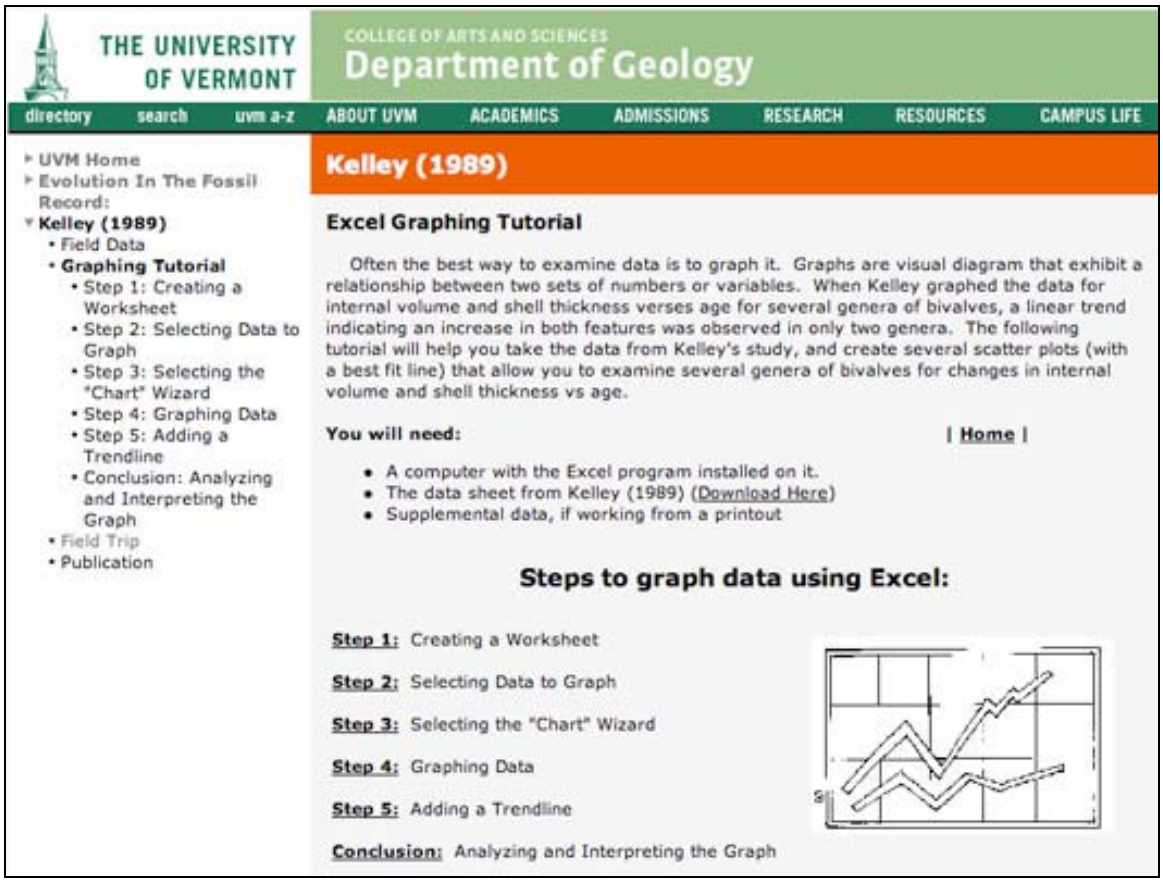

Figure 3.4 Published Data home page

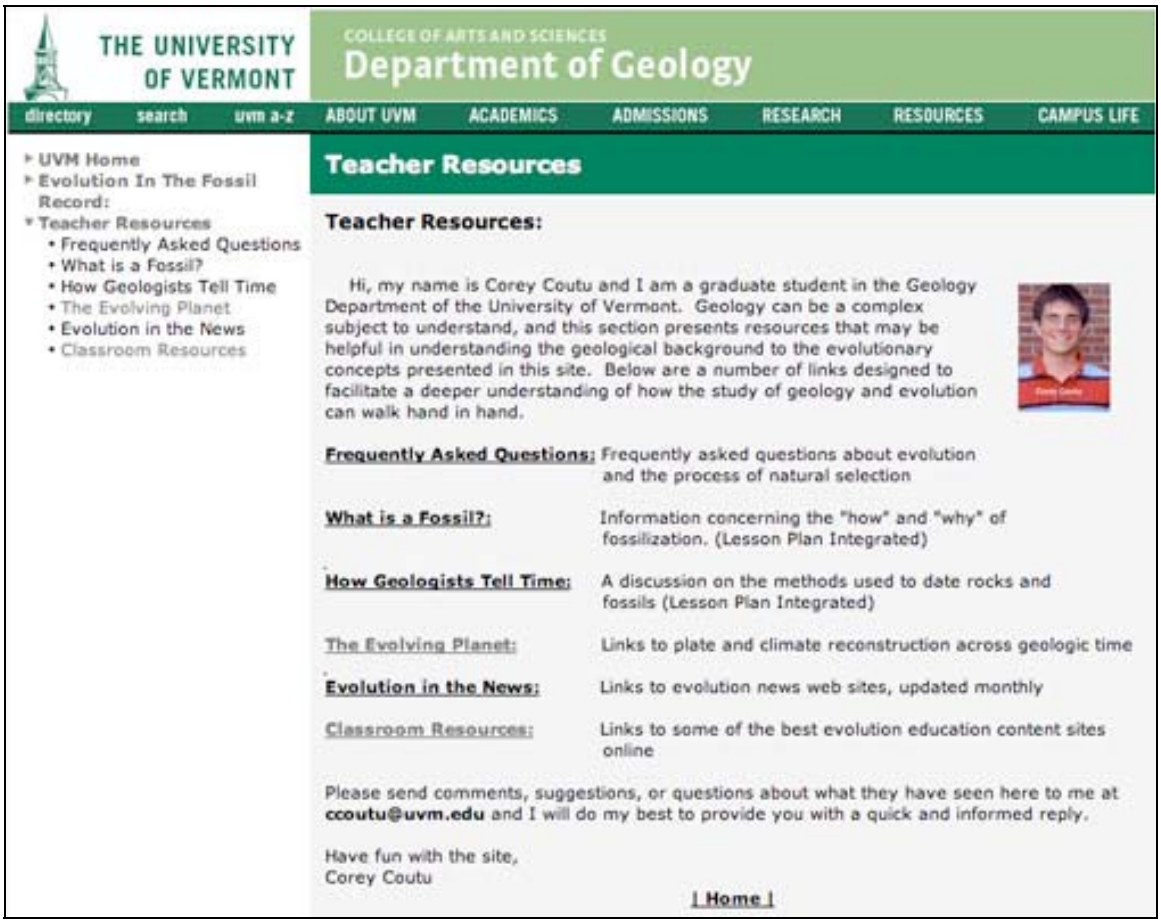

Figure 3.5 Resource Center homepage

Chapter 4: Testing Web Module Effectiveness, a GEOL 005 Classroom Investigation

Introduction

Identified in the GEOL 062 classroom, the successful remediation of naïve knowledge consists of three steps; the identification of naïve knowledge in a population of students, the ability to have students recognize that the notions they hold are naïve, and the creation of curriculum designed to remediate misconceptions through guided learning activities. Educators trained in John Dewey's constructivist teaching philosophy are taught that the identification of naïve knowledge is a vital part of any curriculum design, however even in classrooms where naïve knowledge is identified, misconceptions on evolutionary theory still persist (Bishop and Anderson, 1990). While the identification of naïve notions is the first step in the remediation of misconceptions in the classroom, true conceptual change is dependent on the ability for an educator to alert students to their misconception, and provide the ability for them to examine these misconceptions through guided instruction.

Based on the GEOL 062 classroom experience, a web based teaching module was created utilizing data from Kelley (1989) to create a curriculum that allowed students to examine their misconceptions through the examination of fossil data. Accessible via the Internet, the module was designed as a "distance learning tool", with the ability to be utilized by teachers or students in any number of self guided classroom activities. In order to investigate the effectiveness of utilizing these self-guided activities to remediate naïve notions in the classroom an investigation was conducted to examine if students,

aware of their misconceptions, could change their naïve understandings by utilizing the web module to define, identify, and examine evolutionary change.

Research Population:

The population examined consisted of TAP students (n=16) in the GEOL 005, *Mountain to Lake, Geology of the Lake Champlain Basin* classroom. This class consisted of college freshman, with high school equivalent science education background, and no special training in evolutionary or biological sciences.

Classroom Investigation:

This investigation occurred during a 75-minute lab period, and consisted of a three-step treatment (Figure 4.1). The first step in this process consisted of the identification of student misconceptions via a knowledge survey. This knowledge survey was adapted from Bishop and Anderson (1990), and utilized an examination of key words in a writing sample to infer a naïve, or formal, understanding of evolutionary theory. The second step was made up of the classroom experience, where students worked independently, guided by a worksheet, as they examined evolutionary change in the fossil record. Module focus was directed towards two modules Evolution 101, where students could get a brief recap on the theory of evolution, and the processes by which it operates; and the Virtual Field Trip, where students could use this new information to examine how evolutionary change is quantified and examined in the fossil record. The final step, the assessment (Appendix D), consisted of responding to a question where users were given a word bank and assed to utilize the words when crafting a response to a question on the evolution of mollusks. Using a proxy, where word choice is equated with

conceptual understanding, the correct "formal" usage of keywords in a crafted response would be indicative of the remediation of naïve conceptions, while a naïve response would be indicative of the persistence of naïve conceptions.

Step One: Identifying Misconceptions

The first step in this investigation was the collection of data used to identify naïve knowledge in the classroom. Naïve knowledge was identified using a knowledge survey adapted from Bishop and Anderson, 1990 (Appendix A) and subsequent keyword tally (Appendix B). This knowledge survey was administered one week prior to the classroom visit and lecture as a homework assignment given to students to complete on their own time. Using the proxy of word choice to reflect an understanding of evolutionary concepts the results from the knowledge survey indentified that 58% of student responses reflected a formal understanding of evolutionary theory, while 42% of student responses reflected a naïve understanding of evolutionary theory (Figure 4.2). Once tallied, keywords reflecting naïve understandings, such as "need", "learned", and "changed", were found to dominate student responses, suggesting a naïve teleological / Lamarckian understanding of evolutionary concepts. The percentage of evolutionary concepts found naïve in this study (42%), reflect a similar level of naïve information as the survey administered to GEOL 062 (43%), and work by Bishop and Anderson's (1990) on other college populations (53%).

Step Two: Using the Module

The classroom treatment began with a 20-minute activity designed to introduce students to their misconceptions. This treatment was preformed using a PowerPoint

presentation to display individual questions on the Knowledge survey, students engaged in a discussion on their responses, identifying and correcting the understandings found to be naïve in the initial knowledge survey.

Once classroom misconceptions were introduced and discussed, the students were presented with the worksheet, and were asked to work independently utilizing the website to answer a series of guided questions (40 minutes). This worksheet (Appendix C) was designed to guide learning, focusing first on the tenants of evolutionary theory by examining the "Evolution 101" module, and then building on that understanding by undertaking the "Virtual Field Trip", designed to introduce and examine fossil data to quantify and characterize evolutionary change.

Step Three: Testing the Module

After both sections of the module had been reviewed, student progress was assessed by responding to a question on the evolution of an imaginary group of mollusks (Appendix D). Not only were students asked to answer the question, but they were also asked to include all 16 keywords located in the word box below the assessment question. This word box contained 12 evolutionary keywords and 4 teleological / Lamarckian keywords, making the challenge for the students to correctly utilize both naïve and formal evolutionary keywords in to a well crafted response that correctly expressed how this group of mollusks may have changed over time.

Results:

Once the responses to the summative assessment were tallied, 11 or the 16 responses (68%) were identified as demonstrating a fundamentally correct understanding of evolutionary processes, while 5 of the 16 responses (32%) remained naïve, indicating

the persistence of Lamarckian and teleological concepts. When compared to the results obtained in the knowledge survey, a 10% decrease in naïve knowledge was found to result from this treatment. The drop in naïve responses reflected in the GEOL 005 classroom after instruction support the hypothesis that the module can be used to improve students understanding of evolutionary concepts, however not to the degree found in traditional classroom settings.

Conclusion:

The best procedure to remediate naïve knowledge in a classroom is to identify student misconceptions, introduce students to these misconceptions, and the examination of these misconceptions through guided learning activities in a traditional setting, as identified in the GEOL 062 classroom experience. The results from the GEOL 005 classroom investigation suggest that the independent examination of misconceptions in virtual settings demonstrates an inherent ability to reduce naïve notions in student populations, but to a far more limited extent then the traditional classroom experience. These conclusions suggest that, when incorporated in a short lab activity, the use of virtual learning activities (a distance teaching module) can aid in the remediation of naïve knowledge in the classroom, but is not a good substitute for the traditional classroom approach.

Possible factors that may have influenced some students to retain naive conceptions may include individual differences in vocabulary, and pre-existing knowledge on how evolution operates. While an earnest effort was made to introduce and explain the keywords and process associated with evolutionary theory, especially

those utilized in the assessment tool, questions ensued from the class during the assessment activity, about broad definitions of words such as “fitness”, and “stress”, and how they impact the evolution of a species. A second round of assessment with a modified tool, outlining and defining explicitly each word and definition utilized in the assessment process, would be usefully in extrapolating the extent to which this pre existing knowledge of evolutionary concepts affected assessment results.

Geol 005 Research Treatment:

Step One : Identifying Misconceptions

- Knowledge Survey: HW Assignment (Appendix A)

Step Two : Using the Module

- Introducing Students to Misconceptions: 20 min (Survey Results)
  - Evolution 101: 40 min (Web Based)
  - Virtual Field Trip

Step Three: Testing the Module

- Summative Assessment 15 min (Appendix D)

Figure 4.1 Three Step Treatment for GEOL 005 Class

Keywords	Pre Survey
Evolutionary	
Generation	10
Variation	2
Mutation	9
Population	4
Reproduction	15
Species	1
Adaptation	18
Fitness	8
Genes	8
Competition	0
Total	**75**
Teleological	
Want	1
Desire	4
Need	15
Individual	7
Purpose	11
Total	**38**
Lamarckian	
Use	2
Learned	12
Changed	2
Total	**16**
Total Keywords Identified	**129**

Figure 4.2 Geol 005 Pretest Keyword Tally

Chapter 5: Conclusions and Recommendations

Summary of findings

Based on the keyword tally data collected in the GEOL 062 and GEOL 005 classroom investigations, it appears that both traditional and virtual methods of guided instruction can be successfully utilized to reduce naïve notions concerning evolutionary theory in the classroom to some degree.

Initial hypotheses that a curriculum that presented evolution as an equilibration process, while utilizing the Committee on Undergraduate Science Education's curriculum model to identify and correct naïve notions, would improve students' understanding of evolutionary theory was proven correct via the GEOL 062 classroom experience. In this classroom, naïve notions were identified and then treated with a traditional 6-week curriculum that focused on traditional learning activities including classroom discussions, lectures, laboratory activities, and homework assignments. Content was focused exclusively on paleontology and fossil data, and chosen purposefully to emphasize how fossil data can be used to examine and identify evolutionary change. As identified in the knowledge survey before the onset of instruction, naïve conceptions occupied 43% of the classroom's understanding of evolutionary concepts, however were reduced to 0% when assessment questions located classroom final exams were examined.

In order to investigate the hypothesis that a guided distance-learning tool that mimicked the GEOL 062 classroom experience could also be used to remediate naïve

knowledge, the GEOL 005 classroom investigation was conducted. This investigation consisted of student misconceptions being identified and treated over a 75-minute lab period, that included classroom discussions, and a guided, yet individual examination of the web based module. Initial levels of naïve knowledge in this classroom were documented at 42% by the knowledge survey, and reduced to 32%, as identified in the summative assessment. While this data supports the hypothesis that levels of naïve knowledge can be reduced in a classroom through independent guided activities, the module alone does not appear remediate all of the teleological and Lamarckian concepts within the students population. These results indicate that module use would be most beneficial when incorporated in to a traditional classroom setting as either a classroom activity or homework assignment, but not the primary source of conceptual remediation.

Recommendations for future work

Utilizing a traditional classroom setting, the GEOL 062 classroom experience was successful at eliminating 100% of the naïve information in a population of college students by identifying naïve knowledge in the classroom, presenting that knowledge to students, and addressing these misconceptions with guided learning activities focused around the fossil record. Based on the success of this method, a web based teaching module was created that mimicked classroom content. When this module was tested on the GEOL 005 classroom, the data collected suggested the module did demonstrated the ability to remediate naïve knowledge, but to a far less degree then present in the traditional classroom experience.

Further research is necessary to determine (1) what changes to the module would help to improve effectiveness, and (2) what types of misconceptions are not being addressed or identified in the assessment tools. To gather more data on how educators utilize module content quantitative and qualitative data will be collected from a series of survey questions (Appendix E) presented on the web module in exchange for content use. Tallied responses will stem from a written survey associated with the module, that users will be asked to take part in, in exchange for content use. Qualitative data will be collected by educator's responses to five short answer questions, three of which were designed exclusively to gauge users ability to utilize and incorporate module content in to their classrooms, and two of which are designed for educators to provide feedback on module layout, content, and design.

While the longitudinal success of this method to remediate naïve notions is under investigation, this brief investigation into possible classroom applications, suggests that the use of virtual learning activities to remediate naïve notions in the classroom can produce quantifiable reeducations in naïve understandings. While this approach has been found to reduce the amount of naïve knowledge in the classroom, it has investigation has also identified that some student's conceptions appeared unaffected by the treatment. This result suggests that further research on module content, and assessment protocol, would be beneficial to future studies.

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APPENDIX A: Knowledge Survey

Name:

In order to help me understand where everyone is "at" in terms of understanding evolutionary theory, please answer the following questions to the best of your ability. Your answers will NOT be graded, but will be used to determine the effectiveness of the material I present in class next week. Please type a 3-5-sentence response to the questions, and send the answers to me electronically at (ccoutu@uvm.edu). Make sure to place the words (evolution pre-test) in the subject box.

Part I. Please answer the following questions (3-5 sentences):

1. Cheetahs are able to run faster then 60 mph when chasing prey. How would a scientist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 20 mph?

Response:

2. Cave salamanders are blind, having eyes that are non-functional. How would a scientist explain how blind cave salamanders evolved from sighted salamanders?

Response:

Part II. Relative agreement:

Rank your degree of agreement with the pair of following statements, where 1 = a high level of agreement with the statement on the left, and a 5 = a high level of agreement with the statement on the right. An answer of 3 would indicate that you believe both statements are equally correct. Use the toolbar on the right to **bold** and underline your level of agreement, and then briefly (3-5 sentences) explain your answer.

I) The trait of webbed feet in ducks:

Appeared in ancestral ducks Because they lived in water and Needed webbed feet to swim	1 2 3 4 5	Appeared in ducks because of a chance mutation

Explanation:

II) While ducks were evolving webbed feet:

With each generation, most ducks had about the same amount of webbing on their feet as their parents	1 2 3 4 5	With each generation most ducks had a tiny bit more webbing on their feet than their parents

Explanation:

III) If a population of ducks were forced to live in an environment where water for swimming was not avalible:

Many ducks would die because their feet were poorly adapted to this environment	1 2 3 4 5	The ducks would gradually develop non-webbed feet

Explanation:

IV) Population of ducks evolved webbed feet because:

More successful ducks adapted To their aquatic environment	1 2 3 4 5	The less successful ducks died without producing offspring

Explanation:

APPENDIX B: Keyword Tally Sheet

Keywords	Documented Use
Evolutionary	
Generation	
Variation	
Mutation	
Population	
Reproduction	
Species	
Adaptation	
Fitness	
Genes	
Competition	
Teleological	
Want	
Desire	
Need	
Individual	
Purpose	
Lamarckian	
Use	
Learned	
Changed	

APPENDIX C: GEOL 005 Guided Worksheet

Evolution Worksheet:
Corey Coutu, UVM
For use with the website: http://www.uvm.edu/perkins/evolution/

Part 1: The History of Evolutionary Theory

1. Using the names on the Left, define who the person is, and what they contributed to the current theory of evolution **(Evolution 101 Module).**

Founding figure:	Who they are, and their contribution to evolutionary theory:
Nicholas Steno:	
Charles Lyell:	
Charles Darwin:	
Watson and Crick:	

2. Many people say that evolution is just a "theory", does this mean that the theory of evolution is not real, or unproven?

3. What are the four tenants of the theory of Natural Selection? How do they work together to cause change over time?

4. How can the fossil record be used to examine evolution? What requirements are necessary to document these changes over time?

Part 2: Examining Data

- Go to the **Virtual Field Study** link on the web module homepage http://www.uvm.edu/%7Eccoutu/evolution/fieldtrip/chesapeake/

- Examine the module by clicking the (**Next**) buttons, until you come to the **Graphing Data/ Looking For Trends** section. Click on the "**Graph data from the study**" link

- Follow the tutorial links on this page, and construct a pair of scatter plots, one for the internal volume measurements for *Astarte*, and one for the internal volume measurements for *Corbula*.

- For each graph go to the tool bar, select **Chart,** and choose **Add Trend line**. Select the **Linear Regression** type. (Note: Make sure to choose options and click on display R squared value on graph)

- For each of the plots graphed, answer the following questions:

    1. How have these graphs been adjusted for ontogeny, or the fact that the shell might represent individuals of different ages, and not evolutionary change over time?

    2. Do the graphs demonstrate any trends? (A trend is defined as a statistical tendency for a patter to drift in one direction). If this is the case, then is the data trending towards a larger or smaller internal volume over time?

    3. If trends are found then how you can you prove that these tends reflect evolutionary processes? What are the factors might be causing these trends? Do these relationships represent evolution or environmental plasticity?

Part 3: Applying What You Learned

- Answer the following questions after you have completed your examination of the web module.

Pliocene (5.3 Mya) Pleistocene (1.8 Mya)

1. Shown above are a species of gastropod, from oldest to the left, to youngest at the right. The sequence spans the Plio-Pleistocence from a series of progressively younger depositional beds. Using the words located in the word-bank below explain in 3-5 paragraphs how evolution may have occurred within this species.

Variation	Want	Adapt	Gradual
Reproduction	Stress	Inheritance	Purpose
Need	Population	Fitness	Selection
Species	Population Isolation	Time	Individual

APPENDIX D: GEOL 005 Assessment Tool

Evolution Worksheet:
Corey Coutu, UVM
For use with the website: http://www.uvm.edu/perkins/evolution/

Part 3: Applying What You Learned

- Answer the following questions after you have completed your examination of the web module.

Pliocene (5.3 Mya) Pleistocene (1.8 Mya)

1. Shown above are a species of gastropod, from oldest to the left, to youngest at the right. The sequence spans the Plio-Pleistocence from a series of progressively younger depositional beds. Using the words located in the word-bank below explain in 3-5 paragraphs how evolution may have occurred within this species.

Variation	Want	Adapt	Gradual
Reproduction	Stress	Inheritance	Purpose
Need	Population	Fitness	Selection
Species	Population Isolation	Time	Individual

APPENDIX E: Content Use Survey

Thank you for taking the time to answer the following questions. Your responses will allow us to update and modify the website to make it more useful to users. Please email your response to geology@uvm.edu.
(Evolution Survey in Subject Bar)

1) If you used instructional material from the web module, which section of the Web module did you visit: *Evolution 101*, *Teachers Resources*, *Virtual Field Trip* or *Published Data*? If you visited more then one module, in what order did you access them?

If YES you used content please go to question #2, if NO you did not, then go to question #5

2) In the section you visited, did you find material you could use in a lesson plan or learning activity? If so, could you share with us what material was most useful? Could you also briefly share with us on how you might plan to incorporate this material into your curriculum?

3) How do you plan to assess the effectiveness of the material presented? If you have already used the material, how did the students respond to your lesson/unit? Would you do the lesson/unit again?

4) How did you hear about this website and did it meet your expectations?

If you did not visit any of the four modules, please help us revise the site by emailing to us (geology@uvm.edu) your response to the following question:

5) If you were just visiting the site but did not use any of the instructional material, please take a few moments to let us know what you think about its usefulness. Did you find the content correct and up to date? Are there supplemental exercises or material on evolution or background geologic information that should be added or subtracted from the site? Is the site appealing and interesting? Would you recommend it to others?

Thank you for taking the time to help us revise and maintain this website!