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A CURRICULUM STUDY OF EVOLUTION IN SECONDARY BIOLOGY TEXTBOOKS

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ABSTRACT

Evolution is understood as the theory that unifies all of life science. Yet in the United States, students and adults lack a coherent understanding of evolutionary theory. Secondary science textbooks are at the root of this problem. High school biology textbooks present evolution in a disjointed, obscure way that reinforces student misconceptions. An analysis of four biology textbooks published in the last ten years revealed that ambiguous wording, inattention to prior student knowledge, and disjointed presentation combine to create an ineffective tool for teaching evolution. Effective biology education depends upon teaching evolution as a unifying theme of biology and weaving evolutionary theory through all chapters and topics in the textbook. A paradigm shift in biology texts towards teaching biology in the light of evolution will allow for more potent science education, and shape scientifically literate students in generations to come.

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Chapter 1

Introduction

Evolution has long been a contentious issue in the United States. Religious Americans have waged social, legal, and political wars against evolution education in public high schools, either advocating additional instruction on creationism and intelligent design, or trying to remove evolution from the curriculum entirely. The result is that teachers lack curriculum materials that facilitate effective evolution instruction. Publishers try to skirt the line between accurate science content and appeasing the anti-evolution population by muddying evolution content with ambiguous qualifying statements that make evolution sound more like a best guess than a respected, heavily-supported theory. Textbooks published in a hostile social and political climate reflect that hostility, and fail to give enough attention to evolution for fear of the resulting backlash. Evolutionary biologist and geneticist Theodisius Dobzhanksy published a paper titled, “Nothing in biology makes sense except in the light of evolution”, and he was right (Dobzhansky 1973). Without a solid understanding of how evolution explains all observations of living things, high school students are not able to truly understand biology. Textbooks that misrepresent evolutionary theory are not only failing to effectively teach evolution, but failing to effectively teach all of biological science.

This paper analyzes four high school biology textbooks on their treatment of evolution content based on three standards: alignment with the Next Generation Science Standards, connections to other topics in the text, and attention to diagnosing and correcting student misconceptions. Specific examples are given to highlight the issues with textbook content, and

suggestions are made on how to better present evolution in a clear, accurate manner. This paper recommends a paradigm shift from teaching evolution as an isolated concept to teaching evolution as the unifying theme of all biology. Instead of teaching evolution in the second half of the year, evolutionary theory is best taught first, so other content can be taught in the light of evolution. Textbooks that present evolution as the link between all aspects of life science will give students a cohesive framework with which to learn biology. Improved evolution instruction is the key to creating more effective textbooks and increasing scientific literacy in the United States.

Chapter 2

Scientific and Evolutionary Literacy

The importance of science education in creating judicious citizens cannot be overstated. Whatever the specific learning outcomes of science education may be for a particular subject or grade level, the broader goal of teaching science is to strengthen analytical and critical thinking skills in students so that they can actively participate in a democratic society. Teaching science enables students to be critical consumers of information, and to make informed decisions in their best interests, whether those decisions be in the form of choosing medical care, voting, or selecting healthy food. Charles Eliot, who served as the president of Harvard University from 1869-1895, said of science education,

> Effective power in action is the true end of education, rather than storing up of information.... The main object of education, nowadays, is to give the pupil the power of doing himself [sic] an endless variety of things, which, uneducated, he could not do. An education which does not produce in the pupil the power of applying theory, or putting acquisitions into practice, and of personally using for productive ends his disciplined faculties, is an education which missed its main aim. (Eliot, 1898, p. 323-324; DeBoer, 2000, p. 583)

Biology education provides students with the information to shape their decisions in the context of the natural world in which they live, and thus knowledge of biological sciences is a crucial component of an effective citizenry.

Since science education became a part of public school curriculum in the 19th century, its importance in American society has changed. Before the 1950s, science education focused on connecting science to everyday life (DeBoer 200, 584). This goal changed after World War II brought scientific research into the public eye, particularly physics research, with the Manhattan Project and the invention of weapons that changed the war. Now, the American public began to view scientific research as a worthwhile pursuit (DeBoer 2000, 587). Scientists took advantage of this change in the social perception of science to improve the national science curriculum, using the newly formed National Science Foundation as a vehicle to create an updated curriculum (Garrett 2003). These efforts to improve American science education redoubled in earnest after the Soviet Union launched the Sputnik satellite in 1957. Scientists and educators noted that the rate of scientific and technological change was increasing rapidly, and that the science curricula needed to be redesigned to help students keep up. Shifting goals and expanded state and federal control and funding led to continuous changes to the national science curriculum over the following several decades. Most recently, these changes have culminated in the Next Generation Science Standards (NGSS), which is a set of standards aimed at unifying the pedagogy of scientific disciplines in secondary classrooms. Alignment with these standards is used as a metric for assessing effectiveness of textbooks in this paper, as these standards represent the forefront of science education research and a synthesis of best science teaching practices.

Americans have come to view science education and scientific literacy as a key metric in comparing the standing of American students, and the population as a whole, to the rest of the world. Americans' performance on standardized tests in math and science compared to the scores of students in other nations is commonly used as a ranking to quantify the effectiveness of American science education in a global context. One of these international tests, the Program for International Student Assessment (PISA), shows that U.S. students are still "middle of the pack" in math and science education, and lagging well behind many other industrialized nations (Desilver, 2015). The U.S. ranked 20th in science achievement on the 2012 PISA, despite some of the highest spending per student on education (Table 1, p. 10). A PISA analysis by the Organization for Economic Co-Operation and Development found that, "While the U.S. spends more per student than most countries, this does not translate into better performance" (Schleicher, Davidson 2012). The issue of low student science achievement is not one of economics, but an issue of how science is taught in the United States.

Average Score of 15-year-old students on the 2012 Program for International Student Assessment **Scores are reported on a scale of 0 to 1,000. National Center for Education Statistics**					
Hong Kong	555	**Germany**	524	**Czech Republic**	508
Singapore	551	**Taiwan**	523	**Austria**	506
Japan	547	**Netherlands**	522	**Belgium**	505
Finland	545	**Ireland**	522	**Latvia**	502
Estonia	541	**Macao**	521	**France**	499
South Korea	538	**Australia**	521	**Denmark**	498
Vietnam	528	**New Zealand**	516	**United States**	497
Poland	526	**Switzerland**	515	**Spain**	496
Liechtenstein	525	**Slovenia**	514	**Lithuania**	496
Canada	525	**United Kingdom**	514	**Norway**	495

Table 1: Average Score of 15-year-old students on the 2012 Program for International Student Assessment

The United States not only falls short in general scientific literacy, but also in understanding of the theory of evolution. A 20-year study of American attitudes towards evolution asked participants to classify statements about evolution as true, false, unsure, or does not know. The results of national samples were compared from 1985 to 2005, and with international surveys of 32 European countries and Japan between 2001 and 2005 (Miller 2006). The results show a concerning trend of American adults increasingly unsure about evolution, with the percentage of individuals who classified themselves as unsure whether evolution is true jumping from 7% to 21% between 1985 and 2005. The percentage of adults who simply reject evolution fell 9%, from 48% to 39%. Even so, these percentages are higher than all 32 western European nations and Japan, where evolution is less politicized and religious than in the United States. Miller et. al. (2006) found that among adults, 80% or more in Iceland, Denmark, Sweden, and France accepted evolution, and 78% of Japanese adults agreed with evolution. The only surveyed nation with a higher percentage than the U.S. of adults who reject evolution was Turkey. A poll conducted by BBC America and Harris Interactive found similar results. When asked how humans came to be, 11% of Americans cited intelligent design, and 45% claimed that humans were created directly by God, while only 29% said that humans evolved from a previous species (BBC, Harris Interactive 2009). Americans have hugely outdated views of evolution and the origin of species, and nearly half reject evolution outright.

Chapter 3

The Debate

Why is it that Americans struggle to accept evolution and speciation through adaptation and natural selection, while the rest of the world seems to have no problem? The answer is religious fundamentalism. Christian, and specifically Protestant, fundamentalists believe that evolution conflicts with a literalist interpretation of the Bible, and poses a threat to their religion. Miller et al. (2006) used this perspective to explain the gap in evolutionary understanding between western European nations and Japan, and the United States. In the United States, adults who described themselves as religious were less likely to accept evolution than those who described themselves as not religious or ambivalent. The authors note that Christianity and Protestantism look different in Europe and America; in Europe, the book of Genesis is considered allegorical, while in the U.S., Protestants adopt a literalist interpretation (Miller et al., 2006). Religion can extend into the biology classroom and prevent students from fully understanding and accepting evolution. In his book *Teaching about Scientific Origins*, Lee Meadows identifies how American religion interferes with learning evolution in the classroom.

> Students from Christian, Jewish, Muslim, Native American, and other faiths can have belief systems that conflict with evolution. The conflict can be small, creating minor apprehensions, or large, creating distress and resistance to studying evolution...Children raised in religious traditions emphasizing literal readings of their respective holy writings will probably see the most conflict between their faith and evolution. (Meadows 2007).

Fundamentalist Christianity and Fundamentalist Islam explain Miller et. al.’s findings that the United States and Turkey have the lowest evolutionary understanding of all the developed nations surveyed. Literalist interpretations of religious texts are in perceived conflict with science in a way that a metaphorical reading of the Bible or the Quran might not be.

This conflict between religion and evolution has become political in a nation where a major political party so closely aligns itself with Christianity. Dominionism, a term coined by sociologist and journalist Sara Diamond, is, “the tendency among Protestant Christian evangelicals and fundamentalists that encourages them to not only be active political participants in civil society, but also seek to dominate the political process as a mandate from God” (Gagnon 2008). In the last several decades, the GOP has seen marked increase in politicians who heavily incorporate religion into their platforms, and this includes a rejection of evolution on a religious basis. Among the twelve Republican frontrunners in the 2016 Republican presidential primary, not a single one affirmed a belief in evolution; half proposed that creationism and evolution were equally valid theories, and the other half rejected evolution outright (Brinker 2015). According to Republican senator from Connecticut Christopher Shays, “This Republican Party of Lincoln has become a party of theocracy,” (Nagourney 2005). The First Amendment of the Constitution of the United States may make provisions for the separation of church and state, but that has not prevented a melding of political and religious ideologies that permeates local and state legislation.

The systematic degradation of evolutionary theory by Republican politicians has resulted in school board policies and state standards that neglect or reject evolutionary theory. These anti-evolution policies have been challenged in many court cases, most notably the landmark trial *State of Tennessee v. John Thomas Scopes*. Known as the Scopes Monkey Trial, this court battle in 1925 brought the battle between creationism and evolution into the national consciousness. This legal spectacle was contrived in Dayton, Tennessee when locals responded to the American

Civil Liberties Union's plea for a challenger to the Tennessee anti-evolution law (Linder 2000). John Scopes, a Dayton high school biology teacher, volunteered to be tried for teaching evolution in direct conflict with the Tennessee state statute. Scopes's counsel asked for a guilty verdict of violating the anti-evolution statute in the hopes of appealing the verdict to higher courts, where they wanted to challenge the evolution statute on constitutional grounds. Although the verdict was not overturned on constitutionality, the trial struck a blow to creationist theory in schools and set the stage for later cases.

Nearby Kansas also has a history of putting Darwinism on trial. In 1999, the Kansas Board of Education voted to remove all mentions of evolution from the state science curriculum in a move that symbolized the growing creationist movement's increasing traction in state and local government (Gillam 1999). The Kansas Board voted to dismantle evolution education again in 2005 through new science standards that went so far as to include, "a redefinition of science itself, so that it would not be explicitly limited to natural explanations" (Wilgoren 2005). In 2007, the Board voted to reject the amended science standards that no longer included evolution. The Kansas State Board of Education adopted the Next Generation Science Standards in 2013, which include evolution and natural selection; this marks a huge win for science in a state traditionally hostile towards evolution education.

In just the last decade, Pennsylvania had an evolution trial of its own that placed the small town of Dover, near York, in the national headlines. The Dover Area High School science department requested funding from the school board to purchase the textbook *Biology*, by Kenneth R. Miller and Joseph S. Levine. The school board refused on the grounds that the book was, "laced with Darwinism" with "nothing to counterbalance it", according to Bill Buckingham, head of the school board's curriculum committee (NOVA 2007). Instead, the committee proposed that an Intelligent Design textbook called *Of Pandas and People* be made available as a supplementary resource to student because it filled in areas of supposed confusion with Darwin's theory. The school board also voted to require biology teachers to couple their teaching of evolution with a contingency statement that undermined the definition of a theory as nothing more than a hypothesis too riddled with problems to ever become a fact. Teachers refused to read the statement on the grounds that they would not intentionally mislead their students, so an administrator read the statement, which included the following excerpt, to Dover biology classes:

> Because Darwin's Theory is a theory, it is still being tested as new evidence is discovered. The Theory is not a fact. Gaps in the Theory exist for which there is no evidence. A theory is defined as a well-tested explanation that unifies a broad range of observations (*Kitzmiller v. Dover Area School District 1, 2005*).

Tammy Kitzmiller, a Dover parent, and ten other parents filed suit in conjunction with the ACLU against the Dover Area School District on the grounds that including Intelligent Design in the science curriculum was a violation their student's rights to a separation of church and state.

This landmark trial decided the fate of Darwin and Intelligent Design in the classroom. On December 20, 2005, US District Court Judge John E. Jones III decided in favor of the plaintiffs. His 139-page decision determined that, "intelligent design cannot uncouple itself from its creationist, and thus religious, antecedents" and was, as a result, unconstitutional (*Kitzmiller v. Dover Area School District 136, 2005).* The ruling, which asserts that teaching Intelligent Design in public schools is a violation of the Establishment Clause, sets a groundbreaking legal precedent that can be used to prevent the future denigration of evolution in public school classrooms. Key in this decision was witness Kevin Padian, a paleontologist whose expert testimony Jones cited several times in his decision. Padian’s unrebutted testimony on transitional fossils made use of peer-reviewed scientific data in a way the defense could not; he made clear that the lack of transitional forms in the fossil record in no way undermines Darwinian evolution, or gives credence to alternative explanations such as Intelligent Design. Jones notes in the decision that, "Padian bluntly and effectively stated that in confusing students about science generally and evolution in particular, the disclaimer makes students 'stupid” (*Kitzmiller v. Dover Area School District 41, 2005).*

Chapter 4

Teaching through Evolution

Charles Darwin proposed the theory of evolution and the mechanisms of natural selection in his 1859 book *On the Origin of Species*. Natural selection builds upon three well-observed phenomena among populations to create a framework for understanding the morphology, phylogeny, dispersion, and genomes of all life on earth. The first tenet of natural selection is that heritable variation exists in populations of all living organisms, which results in diversity among individuals of a species. The second is that limited resources in the environment will result in competition for resources, and individuals in a population will have differential success in obtaining these resources. More individuals of a species are born in each generation than can survive, and survival will be determined by the ability of individuals to obtain these resources. Third, natural selection combines both of these ideas to assert that individuals with traits more adapted to the environment will be better able to survive and reproduce, resulting in an increased frequency of these adaptive traits. These three principles of natural selection and evolution are more than just Darwin's observations of species; they create a lens through which we can view and understand all of life on earth as a product of these processes. Evolution and natural selection unify Mendel's laws of inheritance, molecular homologies across species, evidence in the fossil record and paleontology, embryological development, population genetics, and genome sequences to create a comprehensive understanding of the natural world.

The importance of *On the Origin of Species* lies not in its assertions, however, but in the avenues of new research it creates. Charles Darwin's seminal work has and continues to give rise to incredible lines of inquiry and development of new knowledge of life sciences, from the field of taxonomy to our understanding of genetics and molecular biology. “It yields not only powerful explanations for the observed diversity of life, but also a cornucopia of testable hypothesis” (Berkman, Plutzer 14, 2012). The power of any theory is that is allows for the creation of diverse and useful predictions. The National Science Teaching Association maintains that effective science instruction should utilize inquiry as the first step in any lesson or unit plan as a means of intellectual engagement for students (Tweed, 2009). An excellent way for students to engage in inquiry-based science is through the plethora of hypotheses that evolutionary science can allow them to create. The process of creating, testing, and supporting (or refuting) hypotheses is key to understanding science as inquiry, and the nature of science itself. Robert Pennock, a professor at Michigan State University, observes that evolutionary science is the best example of the nature of science when done correctly. “We need to be using science to teach about the nature of science,” Pennock said, noting that evolutionary science synthesizes links between observations, explanations, indirect evidence, experimental results, and causes and effects in a way that illustrates science as a process (Olson 16, 2012).

Teaching biology is a difficult task given the scope and depth of the material. Indeed, Robert Yager notes that there are more new vocabulary words in a junior high school or high school biology textbook than there are presented in a language course for the same age group (Groves 1995). The National Research Council advocates that to solve this problem, “we must identify the central concepts and principles that every high-school student should know and pare from the curriculum everything else that does not explicate and illuminate these relatively few concepts” (National Research Council, 1990). As the unifying theory of biology, evolutionary theory should be the metric we use to synthesize, pare down, and organize the content in secondary biology classrooms. When teachers and scientists are writing and designing curricula, teaching with the theme of evolution creates a scope that can help choose specific content. Teaching through evolution becomes intentional. Instructors can easily create connectivity between units by teaching specific topics towards an understanding of evolutionary science. Learning science in the light of evolution is the goal that suffuses throughout the course.

Evolutionary science is an important part of current state science standards, the NGSS, and the College Board's Advanced Placement standards. The restructured AP Biology curriculum that was released in 2015 asserts four "Big Ideas", the first of which is that, "The process of evolution drives the diversity and unity of life" (The College Board, 2015). About 12% of questions on the old AP Biology exams relate to evolution, according to Gordon Uno, who was part of the group that reframed the AP curriculum; after the exam standards were reframed, that number jumped to about 35% (Olson 7, 2012). The Pennsylvania Biology Keystone Assessment Anchors, which inform the state Biology Keystone exams, contain eight major anchors within two thematic modules: Cells and Cell Processes, and Continuity and Unity of Life (Pennsylvania Department of Education, 2014). One of the eight anchors is the "Theory of Evolution", which includes "the mechanisms of evolution" and "sources of evidence for biological evolution" (Pennsylvania Department of Education, 2014). Many national bodies and states consider evolution to be a key topic in secondary science education, and want students to have a solid understanding of evolution when they graduate from high school. Teaching evolution throughout the curriculum as a theme, as opposed to isolating it in stand-alone chapters ensures that students cannot avoid evolutionary science in the classroom. When evolution is taught in one chapter, or just over several days, parents can pull students out of class for those lessons; however, when evolution is taught as a theme of biology, it permeates all aspects of the course, and becomes inescapable as a component of all life science.

Chapter 5

The Textbooks

In this curriculum topic study, I analyze four secondary biology textbooks that were published in 2010 or later for their treatment of evolution. The first book is *Biology* by Sylvia S. Mader and Michael Windelspecht. This textbook has been in use as a curriculum guide for local Pennsylvania high schools' AP Biology courses since its publication in 2010. It organizes information into eight units, and each unit contains several chapters. Four units are centered on evolution: Evolution, Microbiology and Evolution, Plant Evolution and Biology, and Animal Evolution and Diversity. Unit 3: Evolution begins with the history and theory of evolution, starting with Plato and Aristotle and working through scientists whose ideas contributed to Darwin's work. From there, the textbook compares population evolution to macroevolution and speciation, and works through the origin of life, taxonomy, systematics, and phylogeny. Units 4-6 each tackle evolution in different kingdoms. Unit 4 is called Microbiology and Evolution, but includes kingdoms Bacteria, Archaea, Prostista, and Fungi, which far exceeds the micro scale. The evolution of these four kingdoms is lumped together in Unit 4 without transitions. Unit 5 is Plantae, and Unit 6 is Animalia. Mader and Windelspect give more attention to evolution than any other textbook analyzed, both in number of pages and actual content.

The second textbook is Pearson *Biology* by Kenneth R. Miller and Joseph S. Levine. This is the textbook that the Dover Area School Board refused to purchase because of its focus on Darwinian evolution. Unit 5 of 8 is on evolution, with four component chapters: Darwin's Theory of Evolution, Evolution of Populations, Classification, and History of Life (Miller xiii, 2014). This textbook is a lower to middle-level text designed for an introductory course, so the depth of content is minimal, and the nuances of evolutionary theory, such as the full spread of isolating mechanisms that lead to speciation, are not included. Evolution is listed as one of the ten “Big Ideas” in the textbook, which are described as “central themes” that “interlock” throughout all of biology.

The third textbook is the Pearson AP Edition Campbell *Biology* textbook. Earlier editions of this textbook have been used in AP classrooms for decades; this tenth edition, published in 2014, represents the most recently released book in this line. This textbook has the most unique format of any of the four. Instead of starting with the principles of Darwinian evolution, like most textbooks do, the authors begin this topic in Chapter 21: Genomes and their Evolution. It starts with genome evolution at the end of the evolution unit, with the most recent applications of evolution, like the Human Genome Project and interspecies genome comparisons, coming before other evolution content. The idea is to link the previous chapters on gene expression and biotechnology with evolution by placing a chapter on biotechnology as it relates to evolution as the transition. The effect is not quite the same, and students are presented with concepts like gene sequencing before they have adequate context for these complex biotechnology mechanisms. After Chapter 21 begins Unit 4: Mechanisms of Evolution, which includes the standard discussion of Darwin’s theory, population genetics, and the origin and history of life. Unit 5: Evolutionary History of Biological Diversity contains an overwhelming nine chapters, with each chapter (sometimes two) devoted to the evolution of a particular kingdom.

The fourth textbook is the 2015 edition of Holt-McDougal *Biology* by single author Stephen Nowicki. The textbook is organized with 34 chapters spread out between nine units, and each chapter broken into individual “lessons”, labeled as subchapters. Unit 4: Evolution contains three chapters: Principles of Evolution, the Evolution of Populations, and the History of Life.

This is the second textbook aimed at a lower to middle-level introductory high school biology course. Within Chapter 12: The History of Life, the sixth lesson is on primate evolution, which is the only classification group singled out in the chapter for a closer look at evolutionary history. The section would be better placed elsewhere, like at the beginning of Unit 8: Animals, or Unit 9: Human Biology. Placing the discussion of primate and human evolution this early in the text seems reactionary or defensive, as though Nowicki is making the statement of dominance against opponents of evolution.

Alignment with NGSS	
McGraw-Hill *Biology* (2010)	• Text clearly provides multiple lines of evidence to support evolution (HS-LS4-1). • Large emphasis on statistical analysis of evolution. Chapter 16 devoted entirely with Hardy-Weinberg Equilibrium. Links directly to “analyzing and interpreting data” as an engineering practice (HS-LS4-3). • Presents evolution as the foundation for “new hypothesis”, which incorporates the “nature of science” practice (HS-LS4).
Pearson *Biology*, Miller & Levine (2014)	• Written in complete alignment with NGSS. • Contains “lesson-by-lesson correlation”, where each lesson is listed with the corresponding NGSS standard (all Life Science standards are included in this textbook alignment chart) (T 34-46). • Each chapter has “NGSS Teacher Guide” and “NGSS Problem-Based Learning”, where activities to incorporate engineering practices are included.
Campbell Reece *Biology*	• “Concepts” follow learning progression similar to disciplinary core ideas. • Concepts & DCI match up well; for instance, “emphasis on role of each line of evidence relating to common ancestry and biological evolution” becomes broken into concepts that are worded “____ provides foundation for studying evolution” (p. xxxi).
Holt McDougal *Modern Biology* (2015)	• NGSS alignment is not explicitly stated, which is surprising for a text published in 2015. • Inquiry-based learning and engineering practices are totally absent. Activities are limited to highly-structured, superficial analyses, such as interpreting graph data given to students, or a “quick lab” in which students make observations about pieces of a cut-up photograph meant to simulate finding pieces of the fossil record. • “Standards-Based Assessment” at end of chapter mirrors Pennsylvania Keystone questions, not an NGSS-based assessment.

Table 2: Alignment with NGSS

Connections between evolutionary science and other topics in biology	
McGraw-Hill *Biology* (2010)	• Four units (containing 16 chapters) about evolution, with cohesive transitions between them (i.e. protist evolution to plant evolution to vertebrate evolution). • Evolution presented in Chapter 1 as the "unifying concept of biology" (6). • Evolution not mentioned in chapters that aren't explicitly about evolution, despite characterization as unifying theme.
Pearson *Biology*, Miller & Levine (2014)	• Unit 5 of 8 total units is on evolution, but the topic is absent in other units. • Within these chapters, the organization is counterintuitive, with a full chapter on fossils presented two chapters after evidence for evolution. • Opportunities for connections are not utilized, such as the identification of the central dogma of biology. Universality of genetic code is evidence of a common ancestor, and yet when this topic is discussed, evolution is not (370).
Campbell Reece *Biology*	• Separates "Mechanisms of Evolution" and "The Evolutionary History of Biological Diversity" into units, then ties concepts from these into evolution of organisms in the rest of the text (p. xxxi). • Chapter on Human Genome Project between biotechnology and evolution chapters to provide cohesive link between the two topics.
Holt McDougal *Modern Biology* (2015)	• The entire textbook fails to create unification among chapters, and evolution is no exception. • Both evolution and ecology, two concepts that are connected to all other aspects of biology, are isolated within their own units without mention in other chapters, even where mention is warranted (animal and plant diversity). • Teacher's guide focuses on connecting to real-life concepts, like relating liposomes in medicine to the lipid-membrane hypothesis. This "connection" is confusing because it ties to information students have likely not been exposed to before.

Table 3: Connections between evolutionary science and other topics in biology

Confronting previously held and common misconceptions about evolutionary biology	
McGraw-Hill *Biology* (2010)	• Unclear wording gives the impression that natural selection and evolution are the same thing, which actually deepens a prevalent misconception (276-7). • "Criticisms of Evolution" section presents misconceptions with minimal info to correct them (285-6). • Contrasts the scientific definition of the word "theory" with the colloquial definition to clarify that evolution is not a best guess, but really a well-supported explanatory framework (6).
Pearson *Biology*, Miller & Levine (2014)	• Contradictions enhance student misconceptions. Chapter 1 states that theories can be replaced when better explanations are created. Chapter 16 says the only questions are how evolution occurs, not if, implying that this theory defies the previously given definition and will not be replaced in the future. • Contrasts the scientific definition of the word "theory" with the colloquial definition to clarify that evolution is not a best guess, but really a well-supported explanatory framework (13).
Campbell Reece *Biology*	• Does not directly confront any misconceptions with engagement questions, analogies, or points of clarification. • Clarity of language emphasizes scientific definitions of terms used to prevent misconceptions; ex. Explains the effects of random genetic drift and uses example of difference between 1000 and 10 flips of a coin to explain "randomness" scientifically (460).
Holt McDougal *Modern Biology* (2015)	• "Address Misconceptions" section in each chapter. Ex: genetic drift causes bottleneck effect versus genetic drift results from events like bottleneck effect (316). • "Activate Prior Knowledge" section, which creates analogies to events in students' lives, confronts issues students might have where their life experience might not align with chapter content, and how to mitigate that (e.g., a dog breeder uses artificial selection). • Chapter introduction gives teachers diagnostic engagement questions to determine what students already know at the beginning of the chapter.

Table 4: Confronting previously held and common misconceptions about evolutionary biology

Chapter 6

Organization

The most notable problem shared among all four textbooks is the organization of evolution as a singular topic instead of a theme. Each textbook gives particular chapters to evolution, but none succeed in creating a text that uses evolution as a unifying concept. In Chapter 1: A View of Life, Mader and Windelspecht include Section 1.2: Evolution, The Unifying Concept of Biology. The title is deceptive; this chapter is more of an introduction to the unit on evolution than it is an explanation of why evolution provides unification to the study of life sciences, or why it is a key theme in biology that synthesizes a large number of observations. The authors do not mention evolution directly again until Unit 3: Evolution. Even when they mention endosymbiotic theory in Chapter 4: Cell Structure or Function, they say that chloroplasts and mitochondria were likely the products of prokaryotes that were engulfed by eukaryotes, but fail to use the word evolution directly, even though endosymbiotic theory is strong evidence for evolution (Mader 67, 2010). Half of the textbook units are about evolution, and evolution is directly stated as the unifying theme of biology in the first chapter. Even so, evolution is all but absent in the rest of the textbook, and so the idea of evolution as a theme falls flat because it is simply asserted, not demonstrated.

For a book that the Dover Area School Board cited as being “laced” with Darwinism, Pearson Biology does not live up to the hope that evolution is taught as a central theme providing continuity to the study of biology. The first chapter lists ten “Big Ideas” of biology, one of which is evolution; however, evolution is mentioned as an example of a theory when the scientific method is explained in the same chapter, and then not again until Chapter 16 when the unit on evolution begins. A sixteen chapter gap in attention to evolution is not indicative of a major theme of life science. The unit of evolution itself has significant issues with transitions between chapters and overall flow. Chapter 16: Darwin's Theory of Evolution has a section for evidence of evolution. Two chapters later is Chapter 19: History of Life, with the main idea listed as, "How do fossils help biologists understand life on earth?" (Miller xiii, 2014). Separating out fossils from evidence for evolution is counterintuitive, especially when no other line of evidence for evolution is given its own section or chapter.

Holt-McDougal's 2015 Biology misses many opportunities for cohesive incorporation of evolution throughout the textbook. Even though Nowicki lists evolution as one of just four main ideas in biology, there is no mention of evolution between the designation of evolution as a key idea in biology, and Chapter 10: Principles of Evolution. After Unit 4: Evolution, there is again no mention of evolution as a key consideration. Unit 7: Plants includes plant diversity, structure and function, and the growth and reproduction of the plant kingdom. It is illogical to discuss the observable plant diversity on earth without also discussing the ways that plant diversity arose through evolution, and how the diversity and unity of plant species are a result of the evolutionary processes from Chapter 12. The textbook cites evolution as one of four overarching themes of biology in the first chapter and then does not mention it in relation to observations that are a direct result of evolution. This demonstrates that Nowicki is merely fulfilling expectations that a textbook include evolution as a unifying concept, rather than seriously attempting to address evolution as a theme of biology. Nowicki recognizes that evolution is listed in many state and national standards as a unifying theme, and so followed suit, without thinking about how to incorporate those themes into the textbook in any meaningful way.

Chapter 7

Theory

The biggest issue with teaching evolution is use of the word theory. The Oxford English Dictionary defines a scientific theory as, "an explanation of a phenomenon arrived at through examination and contemplation of the relevant facts; a statement of one or more laws or principles which are generally held as describing an essential property of something" (Oxford English Dictionary, 2015). The key component of this definition is that a theory involves the thorough analysis of relevant facts, and is an explanation that gives larger context to scientific laws that were not interconnected before. The theory of evolution is supported by many lines of evidence, and the body of knowledge that supports evolution is growing every day. Evolution explains why fossils of organisms are found sequentially in different geological strata that have a progression of observable traits. For example, paleontologists have found a well-preserved record of the evolutionary transition of an ancient tetrapod species into modern whales. The fossil record is full of transitional fossils, like *Ambulocetus* and *Basilosaurus*, which demonstrate intermediate forms between a tetrapod and whale. Vestigial structures in extant species also provide evidence for evolution. The hind limb of a whale is no longer useful in an aquatic environment, but provides evidence that the ancestor of the whale likely walked on four limbs. Molecular similarities, such as a shared genetic code and gene homologies, show a unity in life that is evidence of a common ancestor. This is just a tiny fraction of the evidence for evolution; the point is that the evidence is plentiful, and increasing, to support evolution, and thus it is classified as a theory. Scientific theories allow scientists to create testable hypotheses, as well, which continuously provide new evidence for the theory.

Theories are the product of many lines of evidence and a synthesis of many facts, although a theory itself is not a fact. Textbooks, however, present the theory of evolution in a completely different light, which muddies the idea of the process of science for most students. A theory is a well-supported, observable phenomenon or set of phenomena, but textbook presentation of the term makes theory sound like it was insufficiently evidenced enough to become a fact, and that facts are the pinnacle of scientific knowledge. "*Theory* is not a sloppy synonym for the word *idea* or *hypothesis* or *notion* or *guess* or *myth* or *legend* or *opinion* or *belief*…Nor is it an antonym of the word *fact*" (Lerner, Bennetta 40, 1988).

The one textbook that adequately handles the word theory is that of Mader and Windelspecht. The authors explain the scientific process in the first chapter as part of their introduction to biological sciences. They state that a theory is, "the ultimate goal of science" because theories join together many well-supported and tested observations and facts to create a new way of analyzing and studying the natural world (Mader 12, 2010). This definition of the world theory is unambiguous and accurate; Mader and Windelspecht do not hesitate to spend half of a page defining a term they know will trip students up. Another effective aspect of this presentation of the word theory is that the authors take the time to directly confront the common misconception that a theory is merely an idea held by some. "In ordinary speech, the word *theory* refers to a speculative idea. In contrast, a scientific theory is supported by a broad range of observations, experiments, and data from a variety of disciplines" (Mader 12, 2010). It is key that students either be provided or led to the comparison between the colloquial use of the word theory and the scientific use of the word theory. Students come from many different backgrounds, all with different amounts of exposure to the life sciences. It is likely that most or all students have heard the word *theory* used casually in conversation to be interchangeable with the word *idea*, but may not have ever encountered the scientific definition of the word. The side-by-side comparison of these two uses, placed early in the book, gives students the chance to confront this potential vocabulary issue before they study evolution, so they are well equipped to accept and internalize all of the evidence for evolution.

Pearson *Biology* also tries to address the distinction between the colloquial definition of a theory and the scientific definition early on in the text, saying "Theory applies to a well-tested explanation that unifies a broad range of observations and hypotheses and that enables scientists to make accurate predictions" (Miller 13, 2014). The authors add the statement that, "a theory may be revised or replaced by a more useful explanation", which has been true in the past of other theories. Phlogiston theory was proposed in 1669 by Johann Joachim Becher to explain combustion. Becher asserted that all combustible materials were made, in part, of phlogiston plus other component materials; the release of phlogiston explained why burnt matter had less mass than the original object (The Editors of the Encyclopaediea Britannica, 2016). This theory was superseded in the late 1700s by Antoine Lavoisier's oxygen theory. Indeed, the idea that a theory can and should be replaced in the face of new and contradictory evidence is core in the progression of scientific knowledge. In an attempt to clarify the debate of evolution, the authors seemingly redefine theory in Chapter 16. After describing Darwin's theory of evolution, Miller and Levine add the statement, "Any questions that remain are about *how* evolution works – not *whether* evolution occurs" (Miller 473, 2014). This statement was intended as clarification to mean that the existence of evolution is not up for the debate the way Biblical literalists might argue. Yet this statement seems to say that the theory of evolution defies the fundamental idea that a theory can be superseded by a new, better theory. Again, intentional, precise language confuses the definition of theory to seem as though it has multiple, conflicting definitions.

In other situations, comparing the word theory to another definition can be detrimental. As in all four textbooks included in this analysis, the word theory is defined in the first chapter of Holt-McDougal *Biology* as part of an explanation of the nature of science. Its author provides a standard definition of a scientific theory as an explanation for a broad range of observations and experimental conclusions, and then says, “In contrast, a scientific *law* describes a truth that is valid everywhere in the universe” (Nowicki 17, 2015). The direct placement of the definitions of theories and laws next to each other, as well as the use of the word “contrast” makes a theory appear less substantial than a law. The definition of theory includes the word “proposed” to sound like the theory is a conjecture, where scientific law is defined as “true” and “valid” in stark contrast; this juxtaposition undermines the significance of a theory as an idea held as a scientific truth. Yet this textbook does provide a helpful example of theory that elucidates how a theory can be useful while still open to change and development. The author describes germ theory as the idea that microorganisms are the disease-causing agents in illness and infection. Originally, germ theory states that, “it must be possible to grow the disease-causing microorganism in a laboratory” (Nowicki 17, 2015). Further investigation shows that viruses and prions do not fit the traditional lens of germ theory because they are not independently living things and must be grown inside another living cell. The changes in germ theory have been a result of fruitful scientific experimentation, and the general idea still stands even though specifics about the theory have changed over time. This example provides students with context about how a theory can at once be an accurate scientific representation of natural phenomena, and also be subject to change and growth. Understanding the way a theory can change and still maintain usefulness is key to ensure students are not mislead by opponents of evolution who try to exploit the word “theory” as an indicator of inherent issues with the theory of evolution.

Chapter 8

Teaching the Debate

The debate about evolution in science classroom rages on across the United States, with states and school boards launching a constant barrage of assaults in the form of curricula and standards that misrepresent evolution. The debate is still present in states and districts where the standards and curricula do include evolution, which is just as dangerous to students' understanding of evolution as teaching alternative 'theories' or ideas about the origins and development of life. Often, this comes in the form of teaching the debate; this is when teachers identify and discuss the controversy surrounding evolution education, and talk about the viewpoints of other groups, even if they are presented as entirely without scientific support. The problem with bringing the debate into the classroom is that it legitimizes the alternative viewpoints, such as creationism and intelligent design, as worthy of scientific consideration. Dedicating science classroom time to talking about non-scientific ideas that really have no relation to evolutionary science is often a well-meaning endeavor by teachers who hope to correct student misconceptions about evolution. Identifying and confronting misconceptions is an important and necessary component of effective science instruction on any topic, and can certainly involve discussing the incorrect conceptions that a student might have in contrast to the correct or accepted scientific concept; however, without incredibly careful language, presenting and refuting alternate ideas to evolution can serve to confuse students even further. Campbell *Biology*, and Miller and Levine *Biology*, both successfully avoid teaching the debate, while still highlighting the important lines of evidence that support evolution. Mader and Windelspecht, and Nowicki, both include the debate, and in very different ways.

Mader and Windelspecht are guilty of discussing challenges to evolution with nonspecific, and incredibly confusing language. At the end of the first chapter on evolution, they provide a section called "Criticisms of Evolution" where they list four of the commonly cited issues with evolution. These statements are as follows:

1. Evolution is a theory about how life originated.
2. There are no transitional fossils.
3. Evolution proposes life changed as a result of random events; clearly traits are too complex to have originated 'by chance'.
4. Evolution is not observable or testable, thus is not 'science'. (Mader 285-286, 2010)

After each of these numbered statements, the authors provide a paragraph or two of scientific evidence to refute these claims, and break down why they are essentially non-issues in the study of evolution. For example, the counter argument following number one is, "Evolutionary biologists are concerned with how the diversity of life emerged *following* the origin of life. Certainly the study of the origin of life is interesting to evolutionary biologists, but this is not the focus of their research" (Mader 285, 2010). The wording of this entire section is problematic. First, the supposed point of argument with evolution is presented as a strong statement. The following refutation where the authors clarify the research on the origin of life reads like a weak qualifier, as though evolution cannot help us understand the origins of life. These criticisms of evolution are presented with the best intentions of identifying common misconceptions and providing faults with those misconceptions. The actual result is that the end of the evolution chapter reads with uncertainty and ambiguity.

Stephen Nowicki provides a different, successful conclusion to the evolution chapter that strengthens the presentation of evolution without sacrificing clarity or capitulating to a discussion of the opposing viewpoints. The author includes a three paragraph conclusion in Chapter 10: Principles of Evolution where he states that new evidence for evolution is constantly being uncovered, and that advancements in technology are providing scientists with new tools to analyze evolutionary relationships on the cellular and genetic scale. “When you consider the number of proteins in a single organisms, the amount of data that can be gathered through molecular evidence alone is overwhelming” (Nowicki 301, 2015). The word “overwhelming” is key in creating a sense that the ongoing development of evolutionary theory is working towards finding and understanding new lines of evidence, not that new ideas are contradictory to evolution. Language, especially the use of diction that incorporates vocabulary words, is integral in creating lasting understanding of evolution. Biologist Robert Pennock maintains that, “The way in which we frame these issues can make a difference in terms of whether they’re going to be accepted” (2012). Purposeful language at the end of the chapter strengthens the idea of evolution in the textbook. Nowicki focuses on supporting evolution rather than attending to the ideas of intelligent design or creationism, which reads with confidence rather than ambiguity.

Chapter 9

Summary

High school biology courses, and by extension textbooks, need to be restructured to include evolution earlier in the curriculum, if not first thing in the course. The NGSS, Pennsylvania Biology Keystone Assessment Anchors, and College Board AP Biology curriculum all agree that evolution is a key theme in biology. Yet current textbooks do not introduce evolution in any serious depth until late in the book, whether that be in Chapter 10 or Chapter 21. The only way that evolution can be effectively woven throughout the content is if it is presented first. That way, all subsequent chapters and topics can be tied back to evolution. A unifying theme is only useful if it can be presented to unify seemingly disparate subjects in a biology course to give students a framework of understanding the continuity of a biology class. Evolution cannot serve as a unifying theme if textbooks present it after a significant amount of material, as it does not work to retroactively unify that material in student's minds.

The language and length of textbooks needs to be reevaluated. The specific wording around evolutionary science is key in either creating understanding or perpetuating misconceptions and confusion. Students are well attuned to language that conveys uncertainty, and will struggle with wording that is not definitive or strong. Textbook authors need to define theory by highlighting the many lines of evidence and experimental conclusions that support an explanation before it becomes a theory to distinguish between the common use of the word theory to mean "best guess", and the scientific use of the word. Textbooks should also support the definition of theory with examples of other theories that are not questioned by the public the way evolution is. Comparing evolutionary theory to cell theory, germ theory, and the theory of relativity will help explain theory as a widely supported explanation. If students have a strong understanding of the definition of a scientific theory, they will be able to view the debate around evolution as an issue with religion, not with the specifics of the theory.

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