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# Misconceptions in middle school life science and strategies teachers can use to change them

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# Misconceptions in middle school life science and strategies teachers can use to change them

## **Abstract**

Misconceptions and alternative conceptions refer to students' "conceptions that are different from those held by the scientific community" (Sungur, Tekkaya, & Geban, 2001, p. 91). All students have misconceptions due to prior experiences they have had. Students' alternative conceptions are problems for educators because they can block new learning (Sewell, 2002). Therefore, teachers play a crucial role in helping students construct new knowledge upon whatever foundation that already exists. This review of literature examines the findings of research regarding misconceptions, common misconceptions that students have in life science, and how teachers can teach difficult concepts so students are more likely to truly understand what they have learned. The author discusses recommendations for teachers and their school district.

MISCONCEPTIONS IN MIDDLE SCHOOL LIFE SCIENCE AND  
STRATEGIES TEACHERS CAN USE TO CHANGE THEM

A Graduate Review of Literature  
Submitted to the  
Division of Middle Level Education  
Department of Curriculum and Instruction  
In Partial Fulfillment  
Of the Requirements for the Degree  
Master of Arts in Education  
UNIVERSITY OF NORTHERN IOWA

By  
Jody L. Fairbanks  
December 2011

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Entitled: MISCONCEPTIONS IN MIDDLE SCHOOL LIFE SCIENCE  
AND STRATEGIES TEACHERS CAN USE TO CHANGE THEM

has been approved as meeting the research requirement for the  
Degree of Master of Arts in Education.

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## ABSTRACT

Misconceptions and alternative conceptions refer to students' "conceptions that are different from those held by the scientific community" (Sungur, Tekkaya, & Geban, 2001, p. 91). All students have misconceptions due to prior experiences they have had. Students' alternative conceptions are problems for educators because they can block new learning (Sewell, 2002). Therefore, teachers play a crucial role in helping students construct new knowledge upon whatever foundation that already exists. This review of literature examines the findings of research regarding misconceptions, common misconceptions that students have in life science, and how teachers can teach difficult concepts so students are more likely to truly understand what they have learned. The author discusses recommendations for teachers and their school district.

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## CHAPTER 1

### Introduction

Why do students fail to learn what they are taught? They construct their own ideas about the natural world before they even go to school (Driver, 1985; Swell, 2002). Sometimes their initial ideas are in line with the scientific community and what is taught in schools. However, in many instances, there is a big difference between the students' ideas and what is scientifically accurate (Driver, Squires, Rushworth, & Wood-Robinson, 1994). Therefore, these initial ideas play a significant role in learning (Driver, 1985). Teachers have to take such misconceptions into account when they design lessons in order for meaningful learning to occur (Driver, 1985).

#### *Description of Topic*

Educators generally agree that students do not enter the classroom with “blank slates,” (p. 26) ready to pick up new information presented to them by teachers (Sewell, 2002). Students come to school with a foundation of knowledge that they have learned from a variety of sources such as personal experiences, events, places, people in their lives, and the media (Driver, 1985; Sewell, 2002). Sewell (2002) also noted that the older the student is, the wider his or her pre-existing foundation is because he or she has had more life experiences. This foundation is the basis for the construction of new knowledge (Sewell, 2002). Additionally, Sewell (2002) states that some students have a knowledge foundation that needs a lot of work. They may have learning gaps that need patching or rocky spots that need smoothed out. Others will have solid foundations upon which to build (Sewell, 2002). The learning gaps and misconceptions that students have



are problems for educators because they can block new learning (Sewell, 2002).

Therefore, teachers playing a crucial role in helping students construct new knowledge upon whatever foundation already exists. Ausubel (1978) summed this up well when he said, “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly” (p. v). Teachers have to determine their students’ prior knowledge in order to design learning experiences that increase students’ understanding.

### *Rationale*

After teaching a unit on plants and their processes, I decided to use the quick write strategy to assess my students’ learning. A quick write is a writing prompt that gives students an opportunity to write quickly, while thinking deeply (Tompkins, 2001). I gave my eighth grade life science students the following writing prompt, “Doug says that plants get their food from the soil. Do you agree with him or disagree? Why?” Students had to write down their thoughts in their science notebooks. I collected their notebooks and was confident that students would disagree with Doug and give written explanations of photosynthesis to justify their answers. That was not the case. Their responses confirmed that many of my students still held misconceptions about that process. For instance, Jake said that plants get their food from fertilizer. A third of my class agreed with Rachel who said, “Plants suck up food and water from the ground. Plants can’t live without soil.” I was really disappointed. I had hoped that my students would have been able to use what they had learned to explain that plants use water,

carbon dioxide, and sunlight to create carbohydrates or food that plants need for growth and other life processes and humans use for nourishment.

Who is to blame for these incorrect explanations that students gave? There are two possible solutions to this question. The first is to pass the blame onto someone else. This is best illustrated by quoting my colleague who stated that 90% of students' mistakes could be attributed to a lack of studying on their part. The problem with this explanation was that I knew that several of my students who had answered incorrectly were high achievers who always tried hard to achieve high grades. Therefore, I sought another explanation for my students' errors.

From my readings in instructional psychology, I became aware of research in the importance of knowledge, misconceptions, and teaching for transfer. Additionally, in a four year long Grant Wood Area Education Agency (GWAEA) workshop called *Science and Math Inquiry Learning Enhancement* (SMILE), the instructors assigned readings over misconceptions and teaching for understanding. At every meeting, they told us to take students' prior knowledge into account. Based on what I had read and my training at GWAEA, it seemed clear to me that my students' problems were attributed to deep-seated misconceptions rather than lack of effort. Thus, I needed to find effective ways to identify my students' misconceptions and locate strategies I could use to change their thinking. Through this review, I searched for information that will help teachers identify typical misconceptions that students have and implement teaching strategies that elicit understanding.

### *Purpose*

Many educators know that students have trouble understanding difficult concepts, but do they know why? This literature review is intended to help teachers understand the prior knowledge their students bring with them to the classroom. It provides an overview of common misconceptions that students are most likely to hold in biological science. This list is meant to give teachers insight into their students' thinking. Second, strategies are identified that teachers can use to make students' prior knowledge visible. Once educators know the common misconceptions, they need developmentally appropriate forms of instruction designed for middle school students. Therefore, the final part of this paper focuses on research-based strategies and methods that teachers can utilize in their classrooms to help change their students' thinking from misconceptions to scientifically accurate knowledge. The intent of this review of literature is to provide a strong research foundation for educators to aid their understanding of misconceptions and how to best address them.

### *Importance of Literature Review*

This literature review is intended to help classroom teachers, administrators, parents, and students understand the role that prior knowledge can play in learning. First, the literature review identifies the major findings of misconceptions research. Second, the review describes common misconceptions that students have about traditional life science topics. Additionally, it describes and explains strategies that teachers can use to identify what their students already know about a topic. Lastly, this literature review will

provide research-based instructional tools that teachers can implement to target misconceptions their students hold.

### *Terminology*

In order for readers to have a common understanding of the terms used in this paper, the following definitions are presented:

**Active transport:** Active transport is when a cell uses energy to move materials through the cell membrane. It includes endocytosis, the process by which cells absorb molecules from the outside by engulfing it with their cell membrane, and exocytosis, when a cell gets rid of particles that are too large to pass through the cell membrane (Fisher & Kibby, 1996).

**Adaptation:** Adaptation is the gradual change of all individuals in the population over a long period of time (AAAS & NSTA, 2001).

**Assessment:** Assessment is a “...means of gathering data about student performance” (Gregory & Parry, 2006, p. 234). Projects, tests, quizzes, observations, performances, and portfolios are examples of assessment. Assessments provide feedback to the student and the teacher and are used to guide instruction (Gregory & Parry, 2006).

**Best practices:** Teaching strategies that “have a sound research base and proven track record in the classroom” (Gregory & Parry, 2006, p. 34) are considered best practices.

**Carrying capacity:** Trefil et al. (2006), define carrying capacity as “the maximum size that a population can reach in an ecosystem” (p. 242).

**Chromosomes:** Chromosomes are the form DNA takes when cells divide (Trefil et al., 2006).

**Cells:** Cells are the basic unit of structure and function in living things (AAAS, 1993).

**Concept map:** Concept maps are "...two-dimensional, tree-like, hierarchical array of concepts" (Fisher, Wandersee, & Moody, 2001, p. 128) that are connected by lines that are labeled with linking words (Fisher et al., 2001).

**Conceptual change approach:** The conceptual change approach is science instruction that is designed to encourage students to change the misconceptions they have. "Starting from their own common sense ideas learners go through a process of conceptual change by refining their own intuitions about the physical world through organizing, reorganizing, or replacing existing conceptual relations" (Alparslan, Tekkaya, & Geban, 2003, p. 134).

**Constructivist learning theory:** "Constructivist learning theory maintains that learning is not the result of teaching; rather it is the result of what students do with the new information they are presented" (Sewell, 2002, p. 24). Truly, "students are active learners who construct their own knowledge" (Sewell, 2002, p. 24). New learning occurs if the new information fits with existing knowledge (Sewell-Smith, 2004).

**Cytoplasm:** Cytoplasm is the thick liquid in all cells that contains nutrients, wastes, and cell structures (AAAS, 1993).

**Differentiation:** Differentiation is when cells specialize to perform specific jobs throughout the body (Berthelson, 1999).

**DNA:** DNA (deoxyribonucleic acid) is the name of the molecule that makes up every chromosome. It is shaped like a twisted ladder (Trefil et al., 2006).

**Food:** A scientist would say that food is an organic compound that living things use as a source of energy for biological processes (Driver et al., 1994). In everyday life, food is something you eat.

**Genes:** Genes are specific sections of DNA that determine a living thing's characteristics (Trefil et al., 2006).

**Graphic organizers:** Graphic organizers are "...visual ways of organizing information or ideas" (Gregory & Parry, 2006, p. 271).

**Metacognition:** Metacognition is a "...reflective practice in which students think about their thought processes" (Gregory & Parry, 2006, p. 272).

**Middle school:** A middle school is a "... school organization containing grades 6 to 8 (and sometimes 5) that, first provides developmentally appropriate and responsive curricular, instructional, organizational, guidance, and overall educational experiences, and second, places major emphasis on 10 to 14 year olds' developmental and instructional needs" (Manning & Bucher, 2001, p. 8).

**Misconceptions and alternative conceptions:** Misconceptions and alternative conceptions are students' "conceptions that are different from those held by the scientific community" (Sungur et al., 2001, p. 91).

**Natural Selection:** Trefil et al. (2006), define natural selection as "the process through which members of a species that are best suited to their environment survive and reproduce at a higher rate than other members of the species" (p. 181).

**Preassessment tools:** Strategies that allow a teacher “to find out what students already know and do not know prior to instruction” (Gregory & Parry, 2006, p. 67) are known as preassessment tools.

**Prior knowledge:** Prior knowledge is the pre-existing knowledge that students bring to the classroom. It acts as a lens through which the students view and absorb new information. It is a composite of who they are, based on what they have learned from both their academic and everyday experiences (Kujawa & Huske, 1995).

**Respiration:** Scientists define respiration as a series of chemical reactions in which oxygen is used to release energy that is stored in food molecules (Driver et al., 1994).

**Scientific Inquiry:** Scientific inquiry is an instructional learning cycle that has five essential features. First, learners must create scientifically oriented questions. Second, they develop and perform scientific investigations. Third, they gather evidence and formulate explanations. Then, students evaluate their explanations. Lastly, learners communicate and justify their proposed explanation to others for review and assess (McREL, 2001).

**Transfer:** Transfer is the ability to apply prior knowledge to a new situation (Committee on Developments in the Science of Learning & National Research Council, 2000).

**Vertebrate:** A vertebrate animal is any animal with a backbone (Trefil et al., 2006).

**Young adolescents:** Young adolescents are students between the ages of 10-15 who experience the physical, psychological, and cognitive changes associated with the early adolescence developmental period, yet who also exhibit tremendous

cultural, gender, developmental, and individual diversity that deserves to be consider by middle school educators who plan educational experiences (Manning & Bucher, 2001, p. 9).

### *Research Questions*

The following questions will be the focus of this review of literature:

1. What are the main findings of the research on misconceptions in science?
2. What are some common misconceptions that students have in life science?
3. How do teachers effectively teach difficult concepts so that students will more likely understand what they have learned?



## CHAPTER 2

### Methodology for Writing a Review of Literature

Since I believe that misconceptions interfere with student learning, I decided that I needed to know more about what the research says about them. I have been involved with *Project Science and Math Inquiry Learning Enhancement (SMILE)* through my Area Education Agency over the past four years and a major emphasis of that project is constructivism and inquiry learning. The project stressed that teachers must build upon students' prior knowledge, but didn't provide much information about the misconceptions students may hold. Additionally, I had taken the class, Foundations of Instructional Psychology with Dr. Elana Joram. Types of knowledge, misconceptions, teaching for conceptual change, and teaching for transfer were major topics that we studied. Due to my work in Project SMILE and my introduction to student learning in the Foundations of Instructional Psychology course, I realized that I needed a better understanding of what my students' prior knowledge consists of and how to address the misconceptions my students have.

I decided to use the format of a review of literature because it seemed to be the most effective way to increase my knowledge of research regarding misconceptions. Throughout my education, I have only had one course that analyzed and discussed current theoretical and scientific knowledge about student learning. I have read and been told that misconceptions need to be addressed, but I have not had knowledge of the research that would support this information. I have also not had explicit instruction in the methods that teachers should use to teach concepts so that students' conceptual

thinking changes from misconceptions to scientifically accurate knowledge. Also, I have found that many of my colleagues have similar issues and questions, even though they have had more classroom experience. A review of literature would be the best way to answer the questions I had concerning misconceptions that students hold and how to address them effectively.

### *Method of Locating Sources*

I located sources by using online access to the Rod Library's electronic databases at the University of Northern Iowa. I also used Internet searches to compile information, EBSCOhost, an online database, the Iowa Content Network, an online collection of evaluations of scholarly articles relevant to education, the National Science Teachers Association (NSTA) website, my local Area Education Association library, and the professional library at my school. I conducted an online search to find primary research documents that provided information about misconceptions in biology. The keywords used in the search included the following: *types of knowledge, constructivism, misconceptions, misconceptions in biology, misconceptions in life science, alternative conceptions, alternative conceptions in science, alternative conceptions and biology, teaching for conceptual change, teaching for transfer, and inquiry in the science classroom.*

After receiving and critically reading the journal articles, I examined the reference lists for articles and books that might have useful information in order to compile a larger list of journal articles and books that were related to misconceptions and the intended

area of research. I continued to use reference lists to find new and important resources as time permitted.

### *Method of Selecting Sources*

Initially, I considered the credibility of the source of the publication and its author. I chose to use publications that were nationally respected and cited in multiple sources. Additionally, the article or book had to provide a significant amount of information that was relevant to my research questions. Also, the date of publication had to be within the last 20 years because the late 1980s were the start of research on misconceptions and the human brain. This is significant because brain-based research has identified teaching strategies that can be used to increase student achievement (Committee on Developments in the Science of Learning & National Research Council, 2000).

### *Procedures to Analyze the Sources*

As I did my research, I highlighted information that related to my research questions. I also took notes on the main ideas from the sources I was reading. Reoccurring themes and patterns were then identified within the articles I collected. The following categories appeared consistently and were related to my research questions: types of knowledge, theories about how students learn, constructivism, history of misconceptions research, research on misconceptions in biology, application of conceptual change theory in the classroom, assessing for conceptual change, inquiry in the science classroom, identifying students' preconceptions, in-class discussions, concept mapping, monitoring and controlling learning, and metacognition. These major themes

were also used to locate additional sources that were relevant to my research questions and to create an outline for the literature review.

#### *Criteria to Include Literature*

I critically examined the sources I found to determine whether they were relevant to the research questions, published within the last 20 years, provided significant information about the topic, and were published by credible sources. The sources that did not fit the criteria were not used in the review of literature. The number of resources was limited to what was available to the researcher.

## CHAPTER 3

### Review of Literature

Constructivist Learning Theory maintains that learning is the result of what students do with the new information they are presented (Sewell, 2002). Truly, “students are active learners who construct their own knowledge” (Sewell, 2002, p.24). New learning occurs if the new information fits with existing knowledge (Sewell-Smith, 2004). “What a student already knows, then, is critical to the learning process” (Sewell-Smith, 2004, p22). If newly presented information does not fit with what a student already knows, then new learning may not occur. In other words, “the pre-existing foundation knowledge can act as a barrier, preventing new information from being learnt” (Sewell-Smith, 2004, p22). According to the Committee on Developments in the Science of Learning and the National Research Council (NRC), this would make any new construction of knowledge very shaky (2000). This can occur when the ideas that students hold are different from those accepted by scientists (Smith, DiSessa, & Roschelle, 1993). These different conceptions generated by students have been called alternative conceptions, beliefs, frameworks, naïve theories, preconceptions, or misconceptions (Smith et al., 1993). Throughout this paper, the term, *misconceptions*, will be used to refer to students’ “conceptions that are different from those held by the scientific community” (Sungur et al., 2001, p. 91). This review of literature was conducted to compile more information regarding the following research questions:

1. What are the main findings of the research on misconceptions in science?
2. What are some common misconceptions that students have in life science?

3. How do teachers effectively teach difficult concepts so that students will truly understand what they have learning?

#### *Main Findings of Misconceptions Research*

The research available on misconceptions has grown in recent years. Scientists have done studies on the human brain and how it learns new information (Committee on Developments in the Science of Learning & NRC, 2000). This has led to some important findings about people learn science and the role misconceptions play in that process. These findings include: 1) Students come to class with misconceptions. 2) Students have misconceptions in every area of biology topic. 3) Misconceptions are stable and widespread. 4) Students alternative views are difficult to change. 5) They originate from diverse personal experience. 6) Students' prior knowledge interacts with what they are being taught. 7) Conceptual change teaching strategies are effective in converting students' thinking to knowledge that is scientifically accurate.

In the past three decades, educators have greatly improved their knowledge of how students learn science (Committee on Developments in the Science of Learning & NRC, 2000). The committee also promoted an increased emphasis on learning for understanding rather than the learning of facts (Committee on Developments in the Science of Learning & NRC, 2000). Students come into the classroom with alternative conceptions about the world that do not coincide with scientific explanations (Sewell, 2002). These beliefs, frameworks, and naïve theories or preconceptions are called alternative conceptions or misconceptions (Smith et al., 1993).

Wandersee, Mintzes, and Novak (1994) reviewed hundreds of articles, and in doing so; they discerned several central assertions of misconceptions research. The first assertion they found in many studies was that students come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events. In other words, before students are even taught in a formal setting, they have developed conceptions that explain the world around them (Wandersee et al., 1994). Through trial and error and observation, people formulate beliefs that help them make sense of their environment and how things work (Wandersee et al., 1994).

Second, students have misconceptions in every area of science (Driver et al., 1994). As cited by Wandersee et al. (1994) there have been over 200 research studies on students' conceptions in biology. Researchers found that students hold alternative views for topics in all areas of biology, including concepts of life, animals, plants, the human body, reproduction, genetics, and evolution, cells, and food webs (Wandersee et al., 1994). For example, students may believe that their blood is blue when it is inside their bodies because that is how it looks through the skin (Wandersee et al., 1994). Others think that plants get their food from the soil when in reality; they make it through the process of photosynthesis (Wandersee, 1983). Students' misconceptions originate in prior learning, either in the classroom or from their personal interactions with the physical and social world (Sewell, 2002).

Third, alternative conceptions can be stable and can cut across age, ability, gender, and cultural boundaries (Wandersee et al., 1994). For example, Wandersee's (1983), cross-age study of photosynthesis involved 1400 U.S. students in grades 5,8,11,

and 14. He asked students to describe where the food comes from that plants need. More than 60 percent of the elementary and secondary students and about half of the college students said that it comes from the soil. In reality, food for plants comes from glucose made through photosynthesis. Wandersee (1983) found that students of all ages, gender, and educational backgrounds held the same misconceptions about plants.

Another assertion that Wandersee, Mintzes, and Novak (1994) found is that misconceptions are tenacious and resistant to change through the use of conventional teaching strategies. Additionally, they discovered that students' alternative conceptions often mirror the early explanations of natural phenomena offered by the scientists and philosophers of the past. For instance, a study done in 1990 by Bishop and Anderson (as cited in Wandersee et al., 1994) found that biology students said that cheetahs needed to run fast for food, so nature allowed them to develop faster running skills. The views of those modern biology students clearly coincide with Lamarck (1774-1829) whose explanation of evolution was based on three principles: needs, use and disuse, and inheritance of acquired characteristics (as cited in Wandersee et al., 1994). The students' thinking mirrored what early scientists thought about evolution.

Wandersee (1983) concluded that misconceptions originate from a diverse set of personal experiences including direct observation and perception, peer culture, and language, as well as in teachers' explanations and instructional materials. Learners construct meaning through everyday use of technical terms and this has a profound impact on their understanding of terms in the scientific sense (Wandersee et al., 1994). Andersson (as cited in Wandersee et al., 1994) pointed out that textbooks are another



potential source of conceptual difficulty because their diagrams or pictures may be inaccurate or hard to understand. Yet another difficulty with misconceptions is that teachers sometimes hold the same alternative views as their students (Sewell, 2002). This would make it impossible for them to create lesson plans designed to help students learn the correct information.

Learners' prior knowledge interacts with the knowledge presented to them through formal instruction (Sewell, 2002). This can result in a diverse set of unintended learning outcomes (Sewell, 2002). Students sometimes misinterpret content presented by their teachers and use it to support their own beliefs (Arnaudin & Mintzes, 1986). For example, in school, biology students learn that blood contains cells. Through life experiences, they perceive that blood is a red liquid. As a result, students combine their two experiences to construct the belief that blood cells float in a red liquid called blood (Arnaudin & Mintzes, 1986). In reality, blood is clear plasma that contains millions of red blood cells, which give the liquid a red appearance (Arnaudin & Mintzes, 1986).

Lastly, misconceptions research suggests that instructional approaches that focus on conceptual change can be effective (Fisher, Wandersee, & Moody, 2000). During the past 15 years, a number of instructional strategies have been developed to shift students' understanding so that it agrees with the scientific community (Fisher et al., 2000). The most successful of these techniques come from conceptual change theory and the constructivist view of learning (Fisher et al., 2000), particularly when the conceptual change strategies rely on the use of basic techniques that are combined to meet the learners' needs.

All in all, misconceptions are held by students and originate in prior learning and life experiences (Wandersee et al., 1994; Sewell, 2002). They are stable, widespread, strongly held, and resistant to change (Wandersee et al., 1994). Students' alternative conceptions can be difficult to alter even with instruction that is designed to address them (Fisher et al., 2000). Since new knowledge is tied to prior knowledge, misconceptions interfere with the learning of new concepts (Sewell, 2002). They make it difficult for students to see the big picture. Misconceptions can act as a barrier that causes students to overlook the connections between scientific concepts and miss their application to daily life (Sungur et al., 2001). Since most learners have misconceptions, teachers need identify them and then use instructional methods designed to dispel them.

#### *Common Misconceptions Students Have in Life Science*

Researchers have conducted more than 200 studies designed to identify common misconceptions that students hold about biological concepts (Wandersee, Mintzes, & Arnaudin, 1989). The concepts already examined include the students' concepts of life, seeds, cells, nutrition, photosynthesis and respiration, reproduction and genetics, which includes DNA and inherited characteristics, growth, natural selection, evolution, ecology, classification, human body, and microbes (Wandersee et al., 1989). These topics, about which students hold misconceptions, are basic to life science, interrelated, and require higher-order thinking. In the next section, each of the concept areas will be examined in more detail to identify some of the common misconceptions that students are likely to hold.

### *The Concept of Living*

Carey (as cited in Driver et al., 1994, p.17) states, “the concept of ‘living’ is linked to the child’s developing conceptual framework about biological processes”. This is validated by Looft (as cited in Driver et al., 1994) who found that half of the seven-year-olds he interviewed knew that living things needed nutrients, but few used the concept of breathing or reproduction in defining living things. Students who were 10 to 15 had a more advanced idea of the concept. They said that living things eat, drink, move, breathe, and grow. Stavy and Wax (as cited in Driver et al., 1994) studied children ages five to 16 and found that almost all children recognize animals as living, but only 30 percent of six-year-olds, and 70-80 percent of 12- to 15-year-olds regarded plants as living. They also found that only half of the children considered eggs to be alive, whereas 60 percent classified seeds as alive. As students get older, they tend to recognize a wider variety of things as living, and they will use more sophisticated evidence for life such as internal structure and physiological functions (Driver et al., 1994).

### *Seeds*

Only slightly more than half of students above the fourth-grade level classify embryos, including seeds and eggs, as part of a living thing (Driver et al., 1994). Many students do not consider a seed to be a plant (Driver et al., 1994). In fact, a seed is a stage in the life cycle of a plant (Driver et al., 1994). Tamir, Gal-Chappin, and Nussnovitz, 1981 (as cited in Driver et al., 1994) investigated the notion of continuity of life in children aged 10 to 14. Although most of the children could place pictures of seed germination or chick embryology into the correct sequences and 85 per cent said that the

seedlings were alive, only 66 percent said that the seeds were alive. It appears that 19 percent did not understand the continuity of life from seed to seedling; they believed in the possibility of living organisms developing from the non-living, stating, “seeds are dead, when we put them in the soil they get food and begin to live” or “larvae change into pupae which are dead and then we get butterflies” (Driver et al., 1994, p. 13). However, most of the children did have a notion of the continuity of life, explicitly stating that if the seed were not alive, it would not be able to grow or expressing the idea that living organisms originate from other living organisms (Driver et al., 1994). In some cases, the latter idea did not prevent children from believing that eggs and seeds are not alive (Driver et al., 1994). However, among rural students in the sample, only one classified eggs and seeds as non-living, indicating that the agricultural experience had an impact on children’s understanding of the life cycle of plants (Driver et al., 1994).

### *Cells*

According to the American Association for the Advancement of Science (AAAS, 1993), students hold many misconceptions about cells and their processes. Research indicates that it is easier for students to understand that the cell is the basic unit of structure, which they can observe, than that the cell is the basic unit of function, which has to be inferred from experiments (AAAS, 1993). Additionally, from their earlier learning about cells, students may have grasped an overly simplified view of the cell, thinking that structures inside cells float in empty space, when, in fact cells are full of cytoplasm, a thick fluid, which contains nutrients, wastes, and cell structures (AAAS, 1993). Also, students often think that all cells are either plant or animal (AAAS, 1993).

Many, of course, are neither, such as fungi and bacteria (Berthelson, 1999). Students confuse cells and molecules and atoms as well (Sewell, 2002). They are not sure what comprises what, and often do not see a hierarchy (Driver et al., 1994). In reality, cells are made of molecules, which are made of atoms (Driver et al., 1994).

Simpson (as cited in Driver et al., 1994) studied the ideas about food held by 249 14- to 15-year-old biology students in six schools, who had all been taught about food and digestion. Three-quarters of the students knew that carbohydrates and proteins are made of molecules but a large majority also thought they were made of cells (Simpson as cited in Driver et al., 1994). Students appeared to think of living things as being made up of cells but not molecules (Simpson as cited in Driver et al., 1994). Finally, students may think that a cell gets all it needs through diffusion (Fisher & Kibby, 1996). However, a cell also needs other transport mechanisms such as active transport, which includes endocytosis, the process by which cells absorb molecules from the outside by engulfing it with their cell membrane, and exocytosis, when a cell gets rid of particles that are too large to pass through the cell membrane (Fisher & Kibby, 1996).

### *Nutrition*

The word *food* has different meanings in everyday life and scientific contexts (Driver et al., 1994). The scientist would say that food is an organic compound that living things use as a source of energy for biological processes (Driver et al., 1994). In everyday life, food is something you eat. Based on what they have experienced, children tend to view anything useful that is taken into the body as food, including water, minerals, and in the case of plants, carbon dioxide or even sunlight (Driver et al., 1994).

Students aged “13 or 14, do not grasp....the meaning of the word ‘food’ as a material that serves as a substrate for respiration” (Driver et al., 1994, p.27).

### *Photosynthesis and Respiration*

Scientists define respiration as a series of chemical reactions in which oxygen is used to release energy that is stored in food molecules, while breathing is simply inhaling (Driver et al., 1994). Barras (as cited in Alparslan et al., 2003) suggests that the use of more than one term for a concept by textbooks, such as the terms, *internal respiration*, *external respiration*, *cellular respiration*, *general respiration*, *aerobic respiration*, *respiration*, can create confusion in a student’s mind. He claims that these terms are misleading and imply that respiration can take place outside of the cell (Alparslan et al., 2003).

Bell and Brook (1984), Roth and Anderson (1987), and Anderson et al., 1990, (as cited in Association for the Advancement of Science (AAAS) & National Science Teachers Association (NSTA), 2001) found that some students of all ages hold misconceptions about plant nutrition and photosynthesis. Students think plants get their food from the environment rather than producing it internally through photosynthesis (AAAS & NSTA, 2001). In addition, they believe that food for plants is taken in from the outside (Boyes & Stanisstreet, 1991). Even after traditional instruction, students have difficulty accepting that plants make food from water and air, and that this is their only source of food (Boyes & Stanisstreet, 1991).

Driver et al. (1994) stated that students also might believe that plants do not take in oxygen and use it to break down food, a process known as *respiration*. Many students

think that plants only respire in the dark since photosynthesis occurs in the light (Driver et al., 1994). Driver et al. also noted that students who do refer to respiration in plants do not appear to see it as an energy-providing process for plants. Many think that photosynthesis is the energy-providing process for plants instead of respiration (Driver et al., 1994).

In addition, students tend to confuse respiration and breathing. Haslam and Treagust (as cited in Driver et al., 1994) found that most students think that respiration and breathing are the same thing. Adeniyi (as cited in Driver et al., 1994) showed that children learn from an early age that they breathe oxygen and that oxygen is found in air, which is scientifically accurate. Although they know that air is necessary for life, they have a very limited idea of what happens to air once it is inside the body (Driver et al., 1994). Students are unlikely to connect the body's need for oxygen and the food they ingest (Driver et al., 1994). Therefore, they have trouble understanding respiration, which is the process the body uses to convert food to energy at the cellular level (Driver et al., 1994).

### *Reproduction and Genetics*

When asked to explain how physical traits are passed from parent to offspring, elementary, middle school, and high school students expressed several misconceptions. Some students believe that traits are only inherited from one parent (Deadman & Kelly, 1978; Goldman & Goldman, 1982; Kargbo, Hobbs, & Erikson, 1980; Clough & Wood-Robinson, 1985, as cited in AAAS & NSTA, 2001). Other students believe that certain traits are inherited from the mother, and others believe that the traits come from the father



(AAAS & NSTA, 2001). In reality, traits are inherited from both parents (AAAS & NSTA, 2001). Some students believe in a blending of characteristics (Deadman & Kelly, 1978; Goldman & Goldman, 1982; Kargbo, Hobbs, & Erikson, 1980; Clough & Wood-Robinson, 1985, as cited in AAAS & NSTA, 2001). Middle school and high school students have some understanding that characteristics are determined by a particular genetic code that carries information translatable by the cell, which is scientifically accurate (Trefil, Calvo, & Cutler, 2006). Students sometimes think that only the brain or sex cells have chromosomes (Trefil et al., 2006). However, virtually all cells have chromosomes (Trefil et al., 2006). Some students do not understand the relationship between Deoxyribonucleic acid (DNA), genes, and chromosomes (Trefil et al., 2006). Middle school students will often use the three terms interchangeably when in fact, the three of them exist in a hierarchy (Trefil et al., 2006). Chromosomes are the form DNA takes when cells divide (Trefil et al., 2006). DNA is the name of the molecule that makes up every chromosome (Trefil et al., 2006). Each DNA molecule in turn contains genes, the smaller units of heredity (Trefil et al., 2006).

Additionally, Clough and Wood-Robison's study (as cited in AAAS & NSTA, 2001) found that students of all ages believe that some environmentally produced characteristics or learned traits can be inherited, especially over several generations. In reality, each generation has to relearn or acquire these traits, such as the ability to read or write (AAAS & NSTA, 2001). According to Trefil et al. (2006), students also hold these misconceptions about reproduction: 1) Animals plan their reproductive strategies; 2)



Sexual reproduction must involve a separate male and female organism; and 3) Sexual reproduction must involve mating. In fact, none these are true of all animals or plants.

Trefil et al. (2006), define natural selection as “the process through which members of a species that are best suited to their environment survive and reproduce at a higher rate than other members of the species” (p. 181). According to Brumby’s study and the work of Bishop and Anderson (as cited in AAAS & NSTA, 2001), high school and college students have difficulties understanding the notion of natural selection. A major barrier is their inability to integrate two distinct processes in evolution: 1) the occurrence of new traits in a population; and 2) their effect on long-term survival (AAAS & NSTA, 2001). Many students believe that environmental conditions are responsible for changes in traits, or that organisms develop new traits because they need them to survive, or that they over-use or under-use certain bodily organs or abilities (AAAS & NSTA, 2001). In contrast, students have little understanding that chance alone produces new, heritable characteristics by forming new combinations of existing genes or mutations of genes (Brumby, 1979; Clough & Wood-Robinson, 1985; Hallden, 1988, as cited in AAAS & NSTA, 2001).

### *Growth*

Students sometimes think that living things grow because cells get larger, and they do not understand the role of differentiation of cells (Berthelson, 1999). In reality, cells divide and specialize which causes a multicellular organism's growth (Berthelson, 1999). Students have difficulty discriminating between cell division, enlargement, and

differentiation (Berthelson, 1999). The role of cell differentiation or specialization in growth is poorly understood (Berthelson, 1999).

Also, middle school students know food is related to growing, but they are not aware of how (AAAS & NSTA, 2001). They may think that food is only a source of energy, rather than also being a source of matter for growth (AAAS & NSTA, 2001). The energy gained from food is thought to be for movement or work rather than for all bodily functions (AAAS & NSTA, 2001). Students think that food is whatever nutrients organisms must take in if they are to grow and survive rather than those substances from which organisms derive the energy they need to grow and the material of which they are made (AAAS & NSTA, 2001).

#### *Natural Selection and Evolution*

Students also have trouble understanding that changing a population results from the survival of a few individuals that preferentially reproduce, not from the gradual change of all individuals in the population (AAAS & NSTA, 2001). Clough and Robinson, as well as, Lucas and Brimby (as cited in AAAS & NSTA, 2001) found that middle school and high school students might have difficulties with the various uses of the word, *adaptation*. In everyday usage, individuals adapt on purpose. Students of all ages often believe that adaptations result from some overall purpose or religious design (AAAS & NSTA, 2001). In the theory of natural selection, however, populations change or adapt over generations, inadvertently (AAAS & NSTA, 2001).

### *Ecology*

There are many misconceptions students hold in ecology as well. Although they may have internalized the idea of a food chain, many students do not understand the idea of a food web or the complexities of interactions that occur within a food web (Driver et al., 1994). “Most students interpret food webs in a limited way, focusing only on isolated food chains” (Driver et al., 1994, p.61). Driver et al. found that students tend to focus on linear food chains, rather than on cycles of matter, interdependency, or systems, which include living things, nonliving, and how they interact with each other.

Trefil et al. (2006), define carrying capacity as “the maximum size that a population can reach in an ecosystem” (p. 242). Carrying capacity is another key concept for those who are concerned about the environment. It is troublesome to think that some students view ecosystems as limitless resources (Driver et al., 1994). Misconceptions research related to carrying capacity indicates that some students do not perceive populations as fluctuating around certain population sizes that are dependent on environmental variables (Driver et al., 1994).

Another central theme to ecology is the understanding that organisms exist within a system of interacting biotic and abiotic factors. It is a concern to find that some students believe that an organism will be affected by changes only in populations of organisms to which they are directly related through a food-chain relationship (Driver et al., 1994). Other students have been found to believe that some species are important to an ecosystem while others are not. In reality, each has a critical role to play (Munson, 1994). In addition, many middle school students have trouble thinking of organisms in

relation to populations (Trefil, et al. 2006). They can easily think of the needs of an individual rather than the needs of the whole population (Trefil et al., 2006). Students tend to use the terms, *individual* and *population*, interchangeably (Trefil et al., 2006).

Pupils hold several misconceptions about humans and their relationship with the environment (Trefil et al., 2006). Most students think that they themselves are not part of ecosystems (Trefil et al., 2006). Many children view the lives of humans as separate and different from those of plants, animals, and microorganisms (Trefil et al., 2006). Trefil et al. (2006) state that each living thing is unique, but they all share common needs and characteristics. All species, including humans, live and interact in ecosystems (Trefil et al., 2006). Another naive notion that students hold is that pollution affects a limited area even though it really impacts the whole ecosystem (Trefil et al., 2006). Ecosystems are very complex. Therefore, it is hard for students to fully understand how organisms interact with living and nonliving things in order to survive.

### *Classification*

Students hold misconceptions in the area of classification as well. Bell and Barker, along with Trowbridge and Mintzes (as cited in Braund, 1991) found that children, ages 9 to 11, have a view of animals that is restricted to instances drawn from zoos, pets, and farm animals. This view impacts how students classify unfamiliar animals. A vertebrate animal is any animal with a backbone (Trefil et al., 2006). However, some learners will classify any animals with well-defined head and limbs or a rigid body as vertebrate (Braund, 1991). As a result, some students will tend to group snakes and eels as invertebrates because their bodies are able to bend (Braund, 1991).

They may also classify snakes and fish as invertebrates because they lack external segmentation and limbs (Braund, 1991). Certain invertebrates, such as grasshoppers, may be misclassified as vertebrates because they have segmentation and appendages (Braund, 1991).

Students may also confuse amphibians and reptiles (Trefil et al., 2006). Braund (1991) found that 25% of 12-year olds tended to classify a turtle as a mollusk because it has a shell. In addition, Braund found that students misidentified spiders and woodlice as insects because they have many legs without reference to their number or arrangement. Children in Braund's study seemed to encounter the most problems when phylogenetic features of organisms were unfamiliar to students. They did not have as much trouble with more typical examples for each category (Braund, 1991). For instance, some students had trouble classifying penguins as birds because they do not fly, but could easily identify robins as birds (Braund, 1991). Lastly, they often do not understand the hierarchical nature of scientific classification (Trefil et al., 2006).

### *Human Body*

Research on students' understanding of anatomy and physiology concepts reveals that young children have well-developed ideas about the human body (Wandersee, Mintzes, & Novak, 1994). Wandersee et al. (1994) found that children as young as 10, depict a vast array of internal structures when asked to draw the inside of their body. They commonly include the stomach, heart, brain, muscles, bones, lungs, kidneys, and veins in their illustrations. The location, size, and shape of the organs that children draw are fairly consistent across scientific studies. For example, the heart is often drawn in the

shape of a valentine, and many children say that its job is to clean, filter, or manufacture the blood (Wandersee et al., 1994). In reality, the heart only pumps blood throughout the body (Trefil et al., 2006). Even though all blood vessels are connected to the heart, a large number of students at all levels seem to believe that a separate system of tubes carries air to the heart and other organs (Wandersee et al., 1994).

Older learners have alternative conceptions about the human body as well (AAAS & NSTA, 2001). Middle school students have misconceptions about the digestive and circulatory systems in the human body. Wellman and Johnson (as cited in AAAS & NSTA, 2001) studied students' understanding of the digestive system and found that some students believe that food and water have equivalent nutritional consequences, even though water has no nutritional value (Wellman & Johnson as cited in AAAS & NSTA, 2001). They also think that height and weight are equally influenced by the amount of food eaten, and energy and strength result from exercise or rest, but not from nutrition. Additionally, they may think that energy comes directly from the food they eat (Wellman & Johnson as cited in AAAS & NSTA, 2001). Students often think that digestion is a process in which usable energy is released directly from food (AAAS & NSTA, 2001). Many students do not understand that food must be broken down into other substances in the digestive tract and then transported to various parts of the body in order to be reformed into other substances or burned for energy (AAAS & NSTA, 2001). Another misconception students have about the digestive system is that they often think that the stomach is located much lower in the abdomen than it really is (AAAS & NSTA, 2001).

Gellert (as cited in AAAS & NSTA, 2001) found that upper elementary students could list a large number of organs however; a sizeable proportion of adults have little knowledge of internal organs or their location. For example, few adults can draw the stomach and the liver in reasonable positions (Gellert as cited in AAAS & NSTA, 2001). Many students also think that the urinary bladder is part of the digestive system when in fact; it is a part of the urinary system (Canuel as cited in AAAS & NSTA, 2001).

Sungur et al. (2001) found that studies on the human circulatory system have revealed that students have misconceptions about it, as well. A cross-age study carried out by Arnaudin and Mintzes (as cited in Sungur et al., 2001) showed the prevalence of misconceptions among students about the structure and functions of blood, the heart, circulatory and respiratory relationships, and closed circulation. They found that middle school, high school, and even college students perceive blood as cells suspended in red liquid and red cells lacking an intercellular liquid. Blood is actually a pale yellow tissue made up mostly of plasma that contains red blood cells, white blood cells, and platelets (Trefil et al., 2006). They may also believe that blood is blue when it is inside the body since it looks blue through the skin (Sungur et al., 2001). In reality, all blood is red. Oxygen-poor blood is darker and paler than oxygen-rich blood, which is why it appears blue through the skin layers (Trefil et al., 2006). Additionally, it was discovered that students at any level fail to conceive of the heart as a double pump (Sungur et al., 2001). The most common misconception was the conceptualization of the human circulatory system as an open system when it is actually closed (Sungur et al., 2001).



Additionally, Johnson and Wellman (as cited by AAAS & NSTA, 2001) found that fourth-graders know the brain helps the body parts but do not always realize that the body also helps the brain. Whether upper elementary-school students can achieve this understanding with adequate instruction needs further investigation (AAAS & NSTA, 2001). Upper elementary students attribute the functions of conducting messages, controlling activity, and stabilizing the body to nerves (Gellert as cited in AAAS & NSTA, 2001), but even after traditional instruction about the brain and the nervous system, 5th-grade students do not understand the role of the brain in controlling involuntary behavior (Johnson & Wellman, 1982).

In addition, students sometimes conceive of bones as being solid and unchanging, rather than living and in need of nutrients and oxygen (Driver et al., 1994). All bone is made up of living cells that need energy (Driver et al., 1994). Plus, bone contains different types of tissue that have different densities (Driver et al., 1994). Additionally, students tend to think that bones are not alive because they do not contain cells and they are solid (Driver et al., 1994). They actually do have spaces that allow blood-carrying nutrients to travel throughout the bones, so they are living tissue (Trefil et al., 2006). Finally, older children recognize that the skeleton is a framework necessary for movement and support but fail to mention the other important functions of bones (Driver et al., 1994). In actuality, bones also produce red blood cells, protect internal organs, and store phosphorus and calcium (Trefil et al., 2006).

Lastly, students of all ages focus on the physical dimensions of health and pay less attention to the mental and social dimensions (Trefil et al., 2006). Students associate



good health with food and fitness only (Trefil et al., 2006). Many students may even think that the factors important to good health are beyond their control (Trefil et al., 2006) even though choices they make can have a huge impact on their bodies.

### *Microbes*

Microbes are a major factor in students' health and have a key role in the environment. The terms, *microbes* or *microorganism*, are not used by students (Driver et al., 1994). Driver et al. (2004) found that they frequently use the words, *germ* or *bug*, to label the concept. Sometimes pupils will use the words, *bacteria* and *viruses*, as an alternate to germs, but Maxted (as cited in Driver et al., 1994) found little evidence that students thought of them as being separate, distinct concepts. Only nine percent of the 15 year olds studied by Prout (as cited in Driver et al., 1994) recognized that viruses and bacteria are separate types of pathogens. Students also used the word, *bacteria*, as if it is a singular noun, with no distinction between the singular and plural form (Driver et al., 1994). This makes the study of bacteria difficult because they cannot distinguish the concept of an individual bacterial cell from the idea of a bacterial colony (Driver et al., 1994).

When asked to draw germs, Nagy's (as cited in Driver et al., 1994) children, ages five to seven, drew nothing. In his study, older children tended to draw abstract dots or stars that had appendages similar to insects or spiders. Nagy (as cited in Driver et al., 1994) also found that children applied the term, *bug*, to both microbes and insects. They described them as nasty, creepy things. In Maxted's study (as cited in Driver et al., 1994), 12 and 13 year olds knew that germs are microscopic, light, and can float in the

air. They mentioned a range of places where bacteria can live, but only two students said that they needed a living host. None of his subjects could accurately apply the characteristics of life to bacteria (Maxted as cited in Driver et al., 1994). Nagy (as cited in Driver et al., 1994) also found that British and American children did not know the difference between a communicable and a non-communicable disease. Many of them thought that germs cause all illnesses and that germs enter only through the mouth during eating (Driver et al., 1994). In fact, germs can enter the body through a cut in the skin or through the lungs during breathing (Driver et al., 1994). As students get older, their understanding of the causes of illnesses broadens and they begin to include the malfunctioning of internal organs and systems, poor health habits, and genetics as possible causes (Trefil et al., 2006).

Students associate food decay with microbes in the household but appear to be unaware of the role that microbes play in nature (Driver et al., 1994). Students may hold the misconception that all bacteria cause disease and are bad (Driver et al., 1994). Brinkman's and Boschhuizen's study (as cited in Driver et al., 1994) showed that pupils do not recognize microbes as recyclers of carbon, nitrogen, water, and minerals, in nature. Students also fail to understand that some bacteria help produce food, some are the beginning of food chains, some produce oxygen, some decompose waste, and some fix nitrogen (Trefil et al., 2006). Even after instruction, they did not realize the fundamental importance of microbes to all living things (Trefil et al., 2006).

### *Summary of Student Misconceptions in Life Science*

Misconceptions are students' conceptions that are different from those held by the scientific community (Sungur et al., 2001). They are stable, widespread, strongly held, resistant to change, and difficult to alter even when instruction is designed to address them (Wandersee et al., 1994). Since new knowledge is linked to existing conceptions, misconceptions interfere with learning; they make it difficult for students to make connections (Sewell, 2002). Researchers have identified many misconceptions that students have in the field of life science via hundreds of scientific studies. It is clear from their findings that some students have alternative conceptions in every aspect of biology from cells to humans, and seemingly, everything in between.

### *Effective teaching practices that enhance and deepen students' understanding of difficult life science concepts*

Over the past couple of decades, research in science education has indicated that students hold many ideas that are different from those generally accepted by scientists. These different conceptions generated by students have been called alternative conceptions or misconceptions (Sewell, 2002). According to Sewell (2002), studies aimed at determining students' understanding of biology concepts have revealed many misconceptions. To promote meaningful learning, teachers need to construct lessons that are focused on learning goals, take students' prior knowledge into account, and use methods to eliminate misconceptions they hold (Sewell, 2002). Some effective teaching strategies explained in this chapter include questioning techniques, formative assessment probes, written statements, posters, card sorts, questionnaires, concept maps, the

conceptual change teaching approach, carousel, the inquiry learning cycle, and best practices.

The first thing a teacher must do is uncover what students are thinking. Educators need to bring students' misconceptions to the forefront in order to help them unravel their false ideas. There are wide ranges of techniques available that can be used to do just that. One such technique is the formative assessment probe (Keeley, 2008), which are given to students at the beginning of a unit. They can consist of open-ended questions, also known as quick writes, multiple-choice questions, written statements, posters, card sorts, questionnaires, concept maps, a scenario followed by extended response questions, or checklists comprised of examples and non-examples (Keeley, 2008).

One formative assessment teachers can use is immediately is questioning. Proper questioning techniques force students to clarify, probe, and challenge their current ideas (Muson, 1994). When assessing students, teachers should give students a chance to expose their thinking by using open-ended questions or providing common misconceptions as possible answers on tests (Muson, 1994) or on formative assessments (Keeley, 2008).

Teachers can also use written statements to make students' thinking visible (Driver et al., 1994). Driver et al. (1994) outlined this strategy. First, students are asked to write down five statements about a concept. Then, they write their statements on note cards and pool their ideas in small groups. Next, each group sorts through all of their statements and classify them according to the group's own criteria and present the group's ideas to the rest of the class. This strategy makes students' thinking visible to the

teacher. The teacher should keep these statements, so the class can come back them at the end of the unit to edit them, based on the new knowledge the students have gained.

Besides written statements, posters can be used to expose students' thinking (Driver et al., 1994). Pupils are asked to make posters to answer a question that has been carefully crafted (Driver et al., 1994). This process has two steps according to Driver et al. (1994). First, students discuss their ideas within small groups. Second, they make posters to summarize their ideas. Individual students prepare to report back to the rest of the class. Once again, the teacher should store these posters until the end of the unit, so students can reevaluate their thinking at that time.

Card sorts are another pre-assessment strategy that has been successfully tried in science classes and is simple to use (Driver et al., 1994). Students are given cards that represent examples and non-examples of a topic (Driver et al., 1994). Then, they are asked to sort the cards into two categories (Driver et al., 1994). Driver et al. (1994) states that students should also be asked to explain the reasoning behind the categorization. Teachers need to give students time to readjust their card sorts throughout the unit, based on the new knowledge they gain.

Questionnaires and "predict and explain" strategies can be used as well (Driver et al., 1994, p.9). As outlined by Driver et al. (1994), "Pupils are given pictures of objects and living things. They are asked "Which of the following are living? animals? plants?" (p. 9) Predict and explain is an additional technique that can expose students' prior knowledge (Driver et al., 1994). Students are asked to predict what they think will happen, and then they explain their predictions, and try them out (Driver et al., 1994).

Concept maps can be used to uncover student thinking. According to Fisher et al. (2000), “a concept map is a two-dimensional, tree-like, hierarchical array of concepts” (p. 128) that are connected by lines that are labeled with linking words. A concept map can be read by starting with the top concept and reading down the links and concepts of each branch of the map. How does one create a concept map? According to Fisher et al. (2000), there are several key steps to creating a concept map. First, they state that students should make a list of 12 to 15 concepts central to the current unit of study. Second, students would be asked to write these concepts on individual Post-It notes. Then, they should move and arrange the Post-It notes on a tabletop by putting the broader, more general ones near the top of the table, and moving the more specific ones towards the bottom of the list. Next, Fisher et al. (2000) recommend having students create a handwritten version of the concept map. The text of each concept or example should be written within its own box or circle. Arrows should be added to connect two concepts that are related. After that, students would add cross-links that bridge across branches of the concept map to show important knowledge connections. Cross-links should be drawn as dashed or broken lines, so they stand out from the rest of the links (Fisher et al., 2000). Students would then label all of the arrows with linking words and verbs and their modifiers which link concept to concept to form propositions Fisher et al. (2000). Lastly, Fisher et al. (2000) stated that students should be allowed to edit or revise their concept maps to show how their knowledge has developed.

There are several things that teachers should consider when trying concept maps with their students (Fisher et al., 2000). First, when using concept maps with students,

teachers should inform students that concept mapping was originally designed for use in the science classroom (Fisher et al., 2000). Additionally, Fisher et al. (2000) promoted that students need to know that concept maps are a tool that makes students' knowledge visible. Also, students should be cautioned that it is normal to feel a little frustrated at first because they are trying a new way of learning (Fisher et al., 2000). Teachers should have students construct their first maps over a small topic that everyone knows well, such as a pencil and its function (Fisher et al., 2000). Also, it is helpful if students are allowed to work with a partner the first time they develop a concept map, so they can talk over what goes where and remind each other of the requirements: 1) choose 12 to 15 concepts; 2) write them on post-its; 3) arrange the notes hierarchically; 4) add arrows to connect related concepts; 5) add cross-arrows to show bridges across concepts; and finally, 6) label all arrows with linking verbs, words, or modifiers, and revise as needed (Fisher et al., 2000).

Concept maps, formative assessment probes, checklists, card sorts, quick writes, and the other pre-assessment tools enable teachers to see what students are truly thinking, bringing any misconceptions out into the open (Driver et al., 1994). Once teachers know what their students are thinking, they can use other strategies to help students change their alternative beliefs (Wandersee et al., 2008). The conceptual change approach, the inquiry learning cycle, best practices, and metacognitive learning strategies are tools teachers can use to improve student learning, increase achievement, and help students alter misconceptions they have. (Wandersee et al., 2008).

One way to encourage students to modify their misconceptions is the conceptual change approach (Alparslan et al., 2003). Constructivists describe learning as an active process in which learners become aware of, and reason about, conceptual relations (Sewell, 2002). Starting from their own common sense ideas, learners go through a process of conceptual change by refining their own intuitions about the physical world through organizing, reorganizing, or replacing existing conceptual relations (Alparslan et al., 2003). Alparslan et al. (2003) state that “conceptual change theory, based on Piaget's notions of assimilation, accommodation, and disequilibrium, focuses on conditions where students’ existing conceptions are modified by new conceptions” (p. 133).

What conditions are necessary for students to replace their existing ideals with new ones? First, they must come to terms with their personal beliefs about a phenomenon and identify their misconceptions (Mascazine & McCann, 1999). Next, students should experience dissatisfaction with their beliefs by seeing or experiencing an event that challenges their personal beliefs (Mascazine & McCann, 1999). Mascazine and McCann found that this approach leads students to consider other, more scientific, explanations. In addition, Posner, Strike, Hewson, and Gertzog (as cited in Alparslan et al., 2003) stated that the new concept must provide a better explanation and be understandable, plausible, credible, and they must lead to new insights and have potential for new discoveries.

One of the conceptual change strategies is in the use of conceptual change texts (Hynd, Qian, Ridgeway, & Pickle, 1991). In these texts, the identified misconceptions of



students are given first, and then students are informed of the scientific explanations, supported by examples, to create dissatisfaction (Hynd et al., 1991). Alparslan et al. (2003) found that the conceptual change instruction, which explicitly dealt with students' misconceptions, produced significantly greater achievement in the understanding of respiration concepts.

Another conceptual change strategy teachers can use to alter students' misconceptions is by using in-class discussions, coupled with assessment (Crockett, 2004). Active classroom conversations enable students and teachers to examine ideas, explore them aloud, and reason through them (Crockett, 2004). When educators make time for discussion, they can get a more thorough understanding of each student's interpretation of concepts or facts (Crockett, 2004).

The inquiry learning cycle is another framework that teachers can use in their classrooms to increase student understanding (McREL, 2001). Inquiry learning requires environments and experiences where students can confront new ideas, deepen their understanding, and learn to think logically and critically (McREL, 2001). McRel (2001) has identified the five essential features of scientific inquiry. First, learners must encounter scientifically oriented questions. The questions can come from the teacher or students. However, they should be written as 'how' questions. The second feature of scientific inquiry is that students develop and perform scientific investigations to answer their testable question. Third, they gather evidence and formulate explanations that address the question they were trying to answer. Fourth, students evaluate their explanations in light of alternative explanations, particularly those that reflect current

scientific understanding. Fifth, learners communicate and justify their proposed explanation to others for review and assessment.

In inquiry classrooms, the teacher's role changes from instructor to coach (McREL, 2001). The educator must support their students as active learners as they explore, carefully observe, plan, carry out investigations, communicate their results, propose explanations and solutions, pose questions, and critique their scientific practices (McREL, 2001). According to McREL (2001) teachers in inquiry-based classrooms practice the following methods:

- Concentrate on the collection and use of evidence
- Act as facilitators or guides
- Help students benefit from mistakes
- Model inquiry behaviors and skills
- Use appropriate process vocabulary
- Encourage thoughtful dialogue among students and the teacher
- Pose thoughtful, open-ended questions and help students do the same
- Provide a rich variety of materials and resources for investigation
- Use raw data and primary sources of scientific information
- Assist students with clear oral and written communication
- Allow students to expand upon previous inquiry activities (p.17)

Truly, inquiry-based learning is an effective learning cycle that can take a variety of formats within the classroom (McREL, 2001). McREL (2001) states that inquiry

could be a hands-on investigation, a scientific reading and discussion, a computer simulation, a case study, or scientific research. According to McREL (2001), there are two keys to successful inquiry that teachers should remember. First, student must investigate scientific questions (McREL, 2001). Second, learners should use evidence-based arguments to support their explanations of scientific phenomena (McREL, 2001).

In addition to the conceptual change approach and inquiry teaching framework, there are other effective strategies teachers can use in their classrooms. Marzano et al. (2001) analyzed research on the instructional strategies that increase student achievement. These strategies are beneficial to students because they provide students with the opportunity to learn (Marzano et al., 2001). Marzano et al. (2001) have identified nine such techniques that teachers should implement in their classrooms to help students learn. Marzano et al. (2001) recommended the following techniques (as cited in Gregory & Parry, 2006, p. 47):

1. Comparing, contrasting, classifying, analogies, and metaphors
2. Summarizing and note taking
3. Reinforcing effort and providing recognition
4. Assigning homework and practice.
5. Generating nonlinguistic representations
6. Using cooperative learning
7. Setting objectives and providing feedback
8. Generating and testing hypotheses
9. Providing questions, cues, and advance organizers

To be effective in the classroom, teachers must implement these best practices (Marzano, Pickering, & Pollock, 2001). Best practice includes the use of teaching strategies that have a solid research base and are proven to be effective in the classroom

(Gregory & Parry, 2006). Pedagogical researchers and educational professionals have identified a number of powerful instructional techniques that improve student achievement (Gregory & Parry, 2006). According to Gregory and Parry (2006), these tools can be used across the curriculum and at any grade level. Advanced organizers, concept formation, graphic organizers, carousel brainstorming, and metacognition are some best practice strategies (Gregory & Parry, 2006). Following is a discussion of some of these strategies.

Advanced organizers are short sets of visual or verbal information that provide students with a knowledge framework prior to engaging with specific details (McTighe as cited by Gregory & Parry, 2006). They should be used when a new topic is introduced to activate prior learning (Gregory & Parry, 2006). Videos, stories, maps, word webs, diagrams, and other graphic organizers can all be used to give students insight into the lesson's goals (Gregory & Parry, 2006). According to McTighe (as cited in Gregory and Parry, 2006), "Teachers who introduce new material through the use of advance organizers promote learning because advance organizers help students organize, integrate, and retain the material they have learned." (p. 35)

Concept formation (Taba as cited by Gregory & Parry, 2006) is a thinking strategy in which students organize information and construct meanings for themselves by examining particular examples and non-examples and then developing a generalization or concept that fits the facts. Gregory and Parry (2006) state that teachers should use these steps when using the concept formation strategy:

Students are given a set of data in the form of facts, cases, examples, or non-examples. They then work in small groups to sort and classify the information into groups or categories. Once the information is sorted, they draw inferences, make a generalization, and develop concepts from it. (p. 45)

Graphic organizers are a visual way of presenting information or ideas in a meaningful way (Gregory & Parry, 2006). Gregory and Parry (2006) stated that graphic organizers are charts, diagrams, or pictorial representations of material that allow students to learn material in manageable chunks. When they are combined with cooperative learning, they become powerful classroom tools (Gregory & Parry, 2006). Sunshine wheels, also known as concept wheels, Venn diagrams, fish bone diagrams, T-charts, and targets are a few that can be used in the classroom, according to Gregory and Parry (2006).

Sunshine wheels are one graphic organizer that can be easily implemented. They look like circles with rays extending outward like the rays of the sun (Gregory & Parry, 2006). Students first write the main concept in the middle of the circle and then add descriptors on the rays (Gregory & Parry, 2006). Gregory and Parry (2006), found that sunshine wheels are a useful tool to employ when students are trying to generate the features of a concept prior to creating a definition.

Another useful graphic organizer is the Venn diagram (Gregory & Parry, 2006). According to Gregory and Parry (2006) the Venn diagram originated with a British logician, John Venn, to be used in mathematics. Venn diagrams consist of two or more overlapping circles (Gregory & Parry, 2006). The similarities between two or more

concepts are recorded where the circles overlap and the differences are written in their corresponding circles (Gregory & Parry, 2006).

Fish bone diagrams look like a fish skeleton (Gregory & Parry, 2006). The problem or the desired effect is written in the box that forms the head of the fish (Gregory & Parry, 2006). The possible causes or details are arranged along the fish's bones or ribs (Gregory & Parry, 2006).

Another strategy described by Gregory and Parry (2006) is T-charts. Students begin by drawing a T on a piece of paper (Gregory & Parry, 2006). They then write the two words that they are contrasting above the T (Gregory & Parry, 2006). Below the top line of the T, they list differences between the two concepts (Gregory & Parry, 2006).

Targets are an additional graphic organizer that is easy to use (Gregory & Parry, 2006). They consist of three concentric circles. Gregory and Parry (2006) stated that targets can be used to assess students' work visually, without the use a letter grade or percentage. For example, a successful piece of work would be a bull's eye, a near miss would be the middle circle, a definite miss would be the outer circle, and completely off target would be the area outside all of the circles (Gregory & Parry, 2006). The student could fill the form in as a self-assessment (Gregory & Parry, 2006). Graphic organizers such as the target, make students' thinking visible by giving teachers a "window into students' brains" (Gregory & Parry, 2006, p. 203). Therefore, they are valuable assets in the classroom (Gregory & Parry, 2006).

The carousel activity, a type of brainstorming, is a best practice strategy that works at any age level (Crockett, 2004). According to Crockett (2004), the purpose of

the carousel is to dump all ideas out onto the table for consideration and review.

Crockett (2004) recommends that teachers use the following steps to do a carousel brainstorm: 1) At the start of a unit, students sit at tables in small groups of three or four, and each group receives a poster-size sheet of paper with a question on it. 2) Each group has four minutes to record all of its ideas, right or wrong, onto the paper. 3) At the end of the four minutes, each group moves on to the next table and a new question. 4) The groups again have four minutes to consider the ideas that the previous groups had written on the paper and to add their own ideas. 5) When the groups have returned to their original tables, they consider all of the ideas on their paper and sum up the ideas for consideration and discussion with the rest of the class.

Metacognition refers to awareness and understanding of one's own thinking (Gregory & Parry, 2006). Effective thinkers constantly monitor their own thinking, frequently checking, reassessing, and setting goals (Gregory & Parry, 2006).

"Metacognitive strategies provide students with the tools to monitor their performance before, during, and after a learning activity" (Gregory & Parry, 2006, p.45). Methods of self-assessment include purposeful questions such as, "Why am I doing this? What are the criteria for success? What is the nature of this problem?" (Gregory & Parry, 2006, p. 167) Other metacognitive strategies include journal writing, rubrics, and self-assessment checklists (Gregory & Parry, 2006).

It is clear that teachers should pay attention to best practices and include them in their classrooms because they result in student learning (Gregory & Parry, 2006).

Students learn by constructing personal meaning from the information that is presented to

them (Marzano et al., 2001). When students actively construct and organize meaning for themselves, they understand the information at much deeper levels than when the teacher provides the information (Marzano et al., 2001). One size doesn't fit all; therefore, teachers have to use a variety of instructional strategies in order for students to construct meaning (Committee on Developments in the Science of Learning & NRC, 2000). It takes many forms of rehearsal before true understanding is achieved (Committee on Developments in the Science of Learning & NRC, 2000).

*A Synthesis of the Evidence and Ideas Presented by the Research*

Researchers have identified several central assertions of misconceptions research. One central theme they found is that students come into the classroom with many ideas that are different from those currently held by scientists (Smith et al., 1993). Second, these alternative ideas are known as misconceptions or alternative conceptions (Smith et al., 1993). Third, they originate in prior learning, either in the classroom or from their interaction with the physical and social world (Sewell, 2002). Fourth, students have misconceptions in every area of science and alternative views for every biology topic (Wandersee et al., 1994). Fifth, misconceptions can be stable and widespread across student populations (Wandersee et al., 1994). Sixth, they can also be strongly held and resistant to change (Wandersee et al., 1994). Seventh, due to their strength and flawed content, alternative conceptions interfere with new learning (Wandersee et al., 1994). Therefore, they must be replaced or modified through the use of effective instructional strategies that are designed to confront misconceptions directly (Wandersee et al., 1994).



Additionally, researchers have conducted over 200 studies designed to identify common misconceptions that students hold about biological concepts (Wandersee, Mintzes, & Arnaudin, 1989). The biology concepts already examined include the students' concepts of life, seeds, cells, nutrition, photosynthesis and respiration, reproduction and genetics, which includes DNA and inherited characteristics, growth, natural selection, evolution, ecology, classification, human body, and microbes (Wandersee et al., 1989). They found that students have alternate views for all of these major topics in biology (Wandersee et al., 1994). These topics, about which students hold misconceptions, are basic to life science, interrelated, and require higher-order thinking. Therefore, it is very important that teachers identify what their students know. Then, they can design lessons that help students truly understand the science concepts they are being taught.

Before instruction begins, educators must identify what their students already know. Formative assessment strategies, pre-assessment tools, open-ended questions, carefully written multiple choice questions, extended response questions, checklists, posters, card sorts, questionnaires, predictions and explanations, and concept maps are all tools teachers can employ to elicit students' prior knowledge (Gregory & Parry, 2006). Once teachers know what their students are thinking, they need to identify an effective instructional strategy designed to help students change their thinking so they can comprehend what they are being taught.

There are a variety of methods that teachers can use to promote conceptual change (Wandersee et al., 1994). The conceptual change approach and inquiry learning

cycle are two teaching frameworks that can be implemented in science classrooms to increase student achievement. They are effective ways to organize instruction to combat misconceptions. Once a science teacher chooses the best framework for his/her students, he/she then needs to use a variety of instructional strategies to reach all students.

Advanced organizers, concept formation, graphic organizers, carousel brainstorming, and metacognition are some best practice strategies (Gregory & Parry, 2006) teachers should use to meet the needs of their students and to help them to become successful learners.

## CHAPTER 4

### Conclusions and Recommendations

Educators generally agree that students do not enter the classroom with blank slates, ready to pick up new information presented to them by teachers (Sewell, 2002). Students come to school with a foundation of knowledge that they have learned from a variety of sources such as personal experiences, events, places, people in their lives, and the media (Sewell, 2002). The older the students are, the wider their pre-existing foundations are because they have experienced more (Sewell, 2002). This foundation is the basis for the construction of new knowledge (Sewell, 2002). According to Sewell (2002) some students have a knowledge foundation that needs a lot of work because they have learning gaps that need patching or rocky spots that need smoothed out. Others will have solid foundations upon which to build (Sewell, 2002). The learning gaps and misconceptions that students have are problems for educators because they can interfere with new learning (Sewell, 2002). Therefore, teachers playing a crucial role in helping students construct new knowledge upon whatever foundation already exists (Sewell, 2002). Ausubel (1978) summed this up well when he said, “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach accordingly” (p. v).

This review of literature was conducted to answer the following research questions:

1. What are the main findings of the research on misconceptions in science?
2. What are some common misconceptions that students have in life science?

3. How do teachers effectively teach difficult concepts so that students will truly understand what they have learned?

### *Conclusions*

The first research question sought to explore what the research states on students' misconceptions in science. Researchers have uncovered several central aspects in regards to misconceptions. They found that students come to the classroom with many ideas that are different from those currently held by scientists (Sewell, 2002). These alternative ideas are known as misconceptions or alternative conceptions (Wandersee et al., 1994). They originate in prior learning, either in the classroom or from their interaction with the physical and social world (Wandersee et al., 1994). Misconceptions can be stable and be widespread across student populations (Wandersee et al., 1994). They can also be strongly held and be resistant to change (Wandersee et al., 1994). Due to their strength and flawed content, alternative conceptions interfere with new learning (Wandersee et al., 1994). Therefore, they must be replaced or modified through the use of effective instructional strategies that are designed to confront them (Wandersee et al., 1994). Misconceptions play a key role in students' learning scientific concepts correctly.

The second research question sought to identify common misconceptions that students have in life science. Researchers have conducted more than 200 studies designed to identify common misconceptions that students hold about biological concepts (Driver et al., 1994). The concepts already examined include the students' concepts of life, cells, nutrition, photosynthesis, plants, seeds, respiration, reproduction and genetics (including DNA and inherited characteristics), growth, natural selection, evolution,

microbes, ecology, classification, animals, and the human body (Driver et al., 1994). According to the research, students are likely to hold misconceptions about all major aspects of biology.

Misconceptions have an enormous impact on student learning and academic achievement. Therefore, the last research question was aimed to identify ways that teachers can effectively teach difficult concepts so that students will truly understand. When teachers begin a unit of study or a new concept, the first thing they need to do is identify what their students already know about the topic. Formative assessment strategies, pre-assessment tools, open-ended questions, carefully written multiple choice questions, extended response questions, checklists, posters, card sorts, questionnaires, predictions and explanations, and concept maps are all tools teachers can implement to elicit students' prior knowledge (Gregory & Parry, 2006). No matter which tool a teacher chooses, he/she must be sure to include common misconceptions as possible answers students can choose. In doing so, the educator will get a true picture of students' knowledge and will be able to identify any learning gaps and misconceptions students have.

Once teachers know what their students are thinking, they need to use teaching methods that confront students' misconceptions. Wandersee et al. (1994) found that there are a variety of methods that teachers can use to promote conceptual change. The conceptual change approach and inquiry learning are two frameworks that are effective ways to organize science instruction.

Implementation of an inquiry learning cycle is an easy and effective way to improve instruction and increase student achievement (Marzano et al., 2001). The best way to start is to select one lab that encompasses a topic students have misconceptions about and modify it to fit the stages of inquiry. To begin, the teacher and students brainstorm scientific questions about the topic of the lab (McREL, 2001). The teacher should direct the conversation so that they are written as ‘how’ questions (McREL, 2001). Second, the students develop and perform scientific investigations to answer their testable question (McREL, 2001). Third, they gather evidence and formulate explanations that address the question they were trying to answer (McREL, 2001). Fourth, students evaluate their explanations in light of alternative explanations, particularly those that reflect current scientific understanding (McREL, 2001). Fifth, learners communicate and justify their proposed explanation to others for review and assessment (McREL, 2001). After students have shared their results, the teacher must take the opportunity to reinforce the concepts students are learning. Direct teaching in combination with best teaching practices, metacognitive learning strategies, or graphic organizers is a powerful way to reach students (Gregory & Parry, 2006).

### *Recommendations*

Educators, school districts, and/or state education boards need to narrow their curriculum, so teachers can focus on what is truly important. Teachers should also emphasize big ideas and connections among biology subtopics (AAAS & NSTA, 2001). Additionally, they should help their students make connections between biology and other fields of study (AAAS & NSTA, 2001). Educators need to know the possible

misconceptions that students are likely to hold in their particular science field (Driver et al., 1994). It is important that educators use a variety of strategies such as pre-tests, discussion, concept maps, checklists, or quick writes to identify students' prior knowledge as well and watch for commonly held misconceptions (Gregory & Parry, 2006). In addition, when designing assessments, teachers need to include common misconceptions as possible answers to multiple-choice questions so they really know if their students understand the concepts that have been taught (Driver et al., 1994). Educators need to use instructional approaches that facilitate conceptual change and learning for understanding. These methods include inquiry, concept maps, the conceptual change approach, best practices, graphic organizers, and metacognitive learning strategies (Gregory & Parry, 2006). Lastly, teachers need training in order to implement conceptual change strategies and the inquiry learning method so that they can design effective lessons.

#### *Limitations*

There were a few limitations of this literature review. The number of studies I found limits the generalization of this literature review. Time constraints have limited the number of sources I was able to locate. Lastly, the research I found was carried out mostly with college, high school, or elementary students. I only found two studies that were done with middle school students.

#### *Future Research*

There was a limited amount of current research available that identified misconceptions held by middle school students. Therefore, more research could be done

to identify the alternative conceptions that young adolescents have, specifically for this age group. Additionally, research needs to be done to determine which conceptual change strategies are the most effective with middle school students.

Researchers are constantly uncovering new information about how people learn difficult concepts and the best ways to teach students so learning takes place. Teachers need to take that information to heart and use it to design curriculum and lesson plans with students' prior knowledge in mind. Curriculum needs to be narrow so it allows teachers more time to ensure their students reach mastery of the content. The lesson plans teachers develop should be based on formative assessment data and the learning standards students are to achieve. In doing so, educators will increase student achievement and create opportunities that allow students to move towards a greater understanding of science concepts.



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