# The Physics Necessary for Understanding Photosynthesis

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## Overview

This unit is an attempt to allow students in a mainstream biology class to explore the relationship of light, energy and photosynthesis. After completing this unit students will have a more in-depth understanding of the dual nature of the light, and the importance of light energy to "kick off" the photosynthesis process.

## Rationale

The reform effort in science education is alive in Pittsburgh. I am part of a small team of teachers who are faced with the task of revising what is taught and how it is taught in the general biology course throughout the city. I am continually bringing a number of questions to the forefront of my thinking as I carve out this unit of study. "What am I trying to teach?" "Why is this information or process important?" "How will I attempt to accomplish the set objectives?"

One thing that is a continuous effort on my part is teaching subject matter in a coherent fashion integrating math and other science disciplines so that my students may have a more complete understanding of the concepts. At times I hear, " This looks like math class" or " I didn't think this was chemistry". The fact is, the science is not divided neatly into chemistry, physics and biology. As many of the readers know, all science is intertwined, and one could argue biology is the most complex of all the sciences because true understanding of concepts depends upon an understanding of physics and chemistry. This was not necessarily the case in high school biology prior to the turn of the twentieth century. At that time biology was a concentrated study in classification with heavy emphasis placed upon anatomy.

Biology at the turn of the last century was not loaded with the molecular level biochemistry. Nor was it weighted with information at microscopic level. For example, the best scientists at the time of the Spanish Influenza did not understand the way viruses attacked the body and the mechanism that made people sick.
A more complete understanding of the germ theory did not come until Sir Alexander Fleming serendipitously discovered the benefits of an airborne mold *penicillium notatum*. It would be another ten years before penicillin would be available for commercial use. Penicillin's use in World War II prevented countless cases of infections in soldiers who sustained combat wounds. Today in biology courses this "new" information is taught in addition to the classification system and emphasis on anatomy that was taught over a hundred years before.

With the new information that has been obtained in the last fifty years or so the biology curriculum has become overwhelmed. In the last fifty or more years a very dramatic change has occurred in the area of biology. Beginning in the 1960s as a result of Watson and Crick "cracking" the genetic code, high school biology has moved away from the survey of phyla and description of anatomy and physiology and has moved toward a molecular-level explanation of life; however, the curriculum retained the survey of phyla. The addition of the molecular-level explanation of life has blurred the traditional divisions between biology, chemistry, and physics. Now biology students need to be grounded in chemistry and physics, or at the very least understand that sciences are not compartmentalized to understand many concepts.

As a result of the addition of molecular biochemistry, high school biology has become more abstract and the knowledge more extensive. However the exciting aspect of teaching modern biology is watching my students begin to understand very difficult and complex concepts. Although many of these concepts have become common knowledge for many people in our society, they are still a mystery to many of my students. As a science teacher, I enjoy watching students unlock some of these mysteries for themselves. As the students unlock these mysteries they are developing skills of inquiry abilities. The National Science Foundation has developed standards for teachers and students to better achieve the goal of students *learning* science by *doing* science; by being active learners, the students are developing skills that scientists use every day in solving problems.

Modern biology requires that students have an in-depth understanding of many scientific disciplines as they work together. However communicating to students that to study "life" one must also study how life interacts with non-living forces is a difficult task at best. Communicating that the study at times needs to be done simultaneously is even more difficult.

In writing this unit plan, I concentrated on topics in the current course of study that my students have the greatest difficulty understanding. Next, I tried to determine why these topics are so difficult for my students. Did the difficulty come from the "life" aspect of the topic or did the difficulty come the student's difficulty in integrating another, non-life, area of science?

That is not, however, the only problem that prevents my students from mastering the standards. Abstract concepts are also very difficult for them. For example, it seems to me that my students have great difficulty understanding particles that exist at a sub-light microscopic level. This makes sense to me because none of my students have seen an electron microscope that would enable them to see objects at that level. In fact I myself have never worked with an electron microscope because when I was in college the school's only electron microscope was broken almost my entire semester of cell biology. However an electron microscope still does not give a window to the sub atomic level, only to the sub-cellular level. It is still necessary to help students realize the importance of reactions that occur at a sub-cellular level.

In response to my thinking, I have created a list of three areas that my students struggle to understand. They are as follows: the structure of the atom and how that structure determines its bonding abilities; the movement of particles in and out of the cell membrane; the understanding that light has energy and that energy is absorbed by pigments in a leaf, which then is able to convert the energy and eventually make a carbohydrate.

In this unit, I plan to incorporate how physics is an integral part of that biological process. Because of my study of physics, I would like to create a better understanding of the concept of light and its dual nature and how that dual nature is responsible in part for the energy that fuels the planet.

I deliberately chose to participate in a seminar that I had the least amount of confidence in my content knowledge. I have shied away from taking lots of physics for several reasons. One was my terror of higher-level mathematics. However, now I realize that I must try to replace my fear of physics with a better understanding of physics. This understanding will enable me to provide my students with more meaningful learning experiences.

As I develop this unit plan, I intend to incorporate the principles of learning as outlined in <u>How People Learn</u>. The research in that publication states that people learn best when then misconceptions are addressed at the beginning of a unit of study. The research suggests that if students fail to understand the concepts taught or if the students understand long enough to just pass a test, then the students will revert to their original misconceptions. The research also indicates that to develop competence, students must have a deep foundation of factual knowledge and a strong conceptual framework. The key to mastery of concepts is that information must be converted from a set of facts to usable knowledge. From this framework students organize information into meaningful patterns so that it can be retrieved for problem solving. When concepts are mastered, the information can be used to solve problems. The research indicates that students must monitor their own understanding. This usually takes place internally; however, techniques can be employed in the classroom to teach these meta-cognitive thinking skills. Using this approach, I needed to develop a strategy that addresses various learning styles and provides different opportunities.

With this unit, I want to explore sub-atomic particles and design activities that demonstrate their role through learning opportunities for my students. They will thus learn more about the physics of light, and develop a more complete understanding of photosynthesis. Now that I have identified two topics that trouble my students, I will explore activities to make these concepts more understandable.

When the various biology textbooks introduce the topic of photosynthesis, somewhere the chapter contains a short description of light and energy. The placement of the description does not always seem logical. Depending on the book, the information can be as brief as a paragraph or as much as a page or two. Most contain a picture of the visible spectrum, a description of each wavelength in nanometer, and the verbiage to explain the inverse relationship between the wavelength and energy. At some point the paragraph will explain that light consists of wavelengths. There will be a few paragraphs that explain that light is packaged in photons. This information is usually brief and most of my students read over it, take notes on it, but never internalize it; as a result, they do not understand the mechanism of light in photosynthesis. I will argue that students first need to understand that light has energy and that energy is trapped by plants and then converted to a usable form of energy for biological systems (ATP), before they can understand how energy is used to make carbohydrates that are then used to fuel the entire planet directly or indirectly.

In order for the reader to understand my plan, it is helpful to review historical development in the physics of light. Scientists' understanding of light has been evolving for over three hundred years. The first scientist to write about light and its nature was Sir Isaac Newton in 1686. With his study of optics he reasoned that light consisted of material particles. This was consistent with the view of light that was held by the ancient Greeks. The Greeks thought that light traveled as a stream of tiny particles. However, in the late 1600's Christain Huygens proposed the idea that light acted like a wave, not a stream of particles. This idea was not the prevailing one, and the idea that light was made of particles was the prominent one until Thomas Young, Augustin-Jean Fresnel and others in the early 1800's supported Huygens' ideas. They established the wave theory of light because its wave nature obeys the law $c= v$ where $c$ is the speed of light, is the wavelength and $v$ is the frequency. Thomas Young demonstrated that when light passes through a very narrow opening, light could spread out and interfere with light passing through another. His experiment suggested that light spreads out. His experiment demonstrated that a beam radiates outward at all times. White light is separated into the different colors (=wavelengths) of light by passing it through a prism. Wavelength is defined as the distance from peak to peak (or trough to trough). The energy is inversely proportional to the wavelength: longer wavelengths have less energy than do shorter ones.

The order of colors is determined by the wavelength of light. Visible light is one small part of the electromagnetic spectrum. The longer the wavelength of visible light, the more red the color. Likewise the shorter wavelengths are towards the violet side of the spectrum. Wavelengths longer than red are referred to as infrared, while those shorter than violet are ultraviolet.

Additional information came with the development of quantum physics when Albert Einstein in 1905 wrote about the photoelectric effect. The photoelectric effect is the reaction when ultraviolet light hits the surface of a metal and the light causes electrons to be emitted. He explained that the light was made up of a stream of energy packets that he called photons. Today most physicists agree that light behaves as both particles and a wave. This view of light is an overly simple explanation of complex phenomena. Light behaves both as a wave and a particle. The particle properties are demonstrated by the photoelectric effect. I think that students need to understand this historical perceptive to make their understanding of photosynthesis more relevant.

**Objectives**

It is my objective for this unit to cover both science process skills and science content, as outlined by National Science Foundation Standards on Inquiry. It is my goal that by using an inquiry approach to teaching photosynthesis my students will have a deeper understanding of photosynthesis. At the conclusion of the uint all students should be capable of explaining that plants trap energy from the solar energy, the energy is converted to biology energy, that energy is used to manufacture carbohydrates using carbon from the atmospheric $CO_2$. Oxygen is separated from water and is released as a waste product during this process. Photosynthesis provides an essential connection between the sun and the energy needs of the plant.

It is important that the students understand that energy for life primarily comes from the sun. Plants trap energy by absorbing light energy and using that absorbed energy to form strong covalent bonds between atoms of carbon containing molecules. The energy stored in the bonds is used as a source of energy for life process.

It is necessary for my students to have some understanding that energy is contained in the chemical bonds of food molecules. Energy is released when the bonds are broken and new compounds with lower energy are formed. Cells store this energy in the phosphate bond of a high-energy compound called ATP. The understanding of ATP is not a main objective, but I want my students to understand that ATP is the molecule that cells use for storage of energy, and that energy is obtained after food molecules are broken down and the energy in the bonds is released. In addition students should recognize that as matter and energy flow through different levels of organization of living systems, cells, organs, organisms, communities and between living systems and physical environment, chemical elements are recombined in different ways. Each recombination results in storage and release of energy into the environment as heat. Matter and energy are conserved in each change.

In addition to the life science content objectives, there are several physical science standards that my students will need to understand. Students will need to recognize that waves, specifically light waves, have energy and can transfer energy when they interact with matter. They should also understand that electromagnetic waves include radio waves, the longest, microwaves, infrared radiation, visible light ultraviolet radiation, x-rays and gamma rays, and that the energy of the electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.

It is also important that students become aware that each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to theses amounts.

An additional objective for this unit is for students to realize that scientist do not work in isolation or in a vacuum, but work interdependently and function as a group. Scientists also publish work so that their peers all over the world can critique the research and validate or refute the work done by one group so that the entire scientific community can benefit. As a result of collaboration and cooperation science is advancing more rapidly than ever before.

**Strategies**

The strategies that I plan to use in this unit will keep the students active. However, active as defined in the National Science Education Standards implies physical and mental activities. Having students' hands busy does not guarantee a successful learning outcome if their minds are not "on" the lesson and focused around a problem. The strategies that I will employ in this lesson are based on the Teaching Standards B as defined in the National Science Education Standards.

As I teach this photosynthesis unit, I hope to guide my students' learning by helping them ask questions and predict outcomes and work collaboratively. Allowing them time in class to observe phenomena, collect additional data or information and then reflect upon the information so that they can truly analyze the phenomena, I believe will give a more complete understanding of the phenomena.

I will be using collaborative groups to encourage students to participate in sharing data and in developing group reports. Collaboration among students is essential in the establishment of a community of learners. I will also require a summary of what has been learned to be shared with the class so that the students will be given an opportunity to explain, clarify and justify the information that they have learned. I would hope that the student will take responsibility for his/her own learning as the unit unfolds. It is my intent to create an environment where the students become excited and want to know how photosynthesis works and to investigate the process.

Encouraging *accountable talk* within the groups is essential to the group learning. The talk, stop and listen model will be demonstrated at the beginning of the lesson. This is nothing more than teaching manners and having students use "proper rules of engagement" as I call them. Everyone may have a turn to ask a question or answer a question, but one student at a time may talk. This sounds like something that should not need to be modeled, but in my experience students need constant reminding. My students now correct each other and say "use proper rules of engagement." The outcomes of allowing students to discuss or talk are many. While engaged in accountable talk, I will be looking for the community to expand their knowledge base, and show they are using evidence to answer the questions that develop as the unit expands. In addition I will be analyzing their discussions for evidence of reasoning and rigorous thinking.

In this unit I am planning to allow the students the time, the space and the resources needed for learning science. Allowing the students to grow plants under different colors of light and then have them put together a presentation of the project will give them an opportunity to engage in an extended scientific investigation. Following the National Standards for Science Education, taking into account that people learn by lecture based instruction, skills based instruction, inquiry based instruction, as an individual, within a group setting and enhanced with technology based instruction, I am planning to use all modes of instruction. I am focusing many activities and discussion around inquiry based instruction for this unit with the intent of allowing students time to form questions and then to investigate their questions. Most of the in class work will occur in collaborative learning groups.

**Classroom Activities**

At the start of the unit I will discuss with the students ways to assess or test what they know. We will spend several minutes discussing how I will assess the knowledge that they will have acquired during the two- week period spent on photosynthesis. The extended experiment will take longer for the students to collect data on plants growing under different light sources. The students can begin to put their presentation together during the third week while they are still collecting data. It may be necessary to move on to respiration, the next unit, to allow the plants more time to grow so that sufficient data can be collected and then analyzed. That decision can be made on a case by case basis depending upon the students' ability to work independently. I will introduce the students to the end project expectation. They will have to put together a multimedia presentation of the work that their group has completed during the unit. We will discuss in general the project and more specifics as the unit comes to completion.

I will follow the rubric that was given to the juniors for developing their graduation project. In the end each group will have to present to the class information about their experiment with photosynthesis. The presentation will be assessed on the use of visuals and or media; the students' ability to answer questions from myself as well as classmates; the students' reflection or analysis of the quality of the learning experience; the students' use of language, the delivery of the presentation, the content and organization, as well as the quality of the research that was used to pull the presentation together. Each of the above elements will be scored from categories advanced, proficient, basic or below basic, and assigned a point value 4, 3, 2 or 1. The scores will be averaged and 28 – 36 equals an advanced score, 19- 27 equals a proficient score, 10-8 basic and 1-9 below basic. I will instruct the students that a score of proficient or above is the score that they need to complete the research component of the graduation project. I will also have other groups score their classmates with the same rubric. This will provide an opportunity for all students to be active during the presentations. The student scored rubric will be assigned a point value to ensure that the students take this task serious.

In this unit sufficient time will be spent developing the idea that light has a dual nature. First the students will explore the idea of light as a wave so that they can demonstrate an understanding of visible light and they can make a correlation between visible light and heat absorption. The lesson will allow students to see the colors of the rainbow that are contained in white light. The students will then work in small lab groups of 3- 4 students and conduct a light absorption activity by placing different pieces of colored paper over a thermometer on the windowsill and then have them return to their desks. As a whole group they will make prediction about the temperature change for each colored sheet of paper and record the predictions of the change in temperature on the board. The students will read and record the temperatures shown on each thermometer from their group. The students will create a data table and create a graph that illustrates the changes in temperature. I will coordinate the students to share, compare and discuss the results, and compare actual results with the predictions that had been recorded on the board. The students will draw conclusions about how color affects light absorption.

When the activity is complete students will write a formal lab report based on the activity that will be placed in a communication portfolio. I have found that keeping student portfolios can be greatly simplified by starting at the beginning of the year and placing all the students' formal lab reports in them. Having the students write formal laboratory reports may also help them realize that good communication skills are essential for scientists to communicate the phenomena that they encounter so that the information can be easily shared with the scientific community and the general population.

After this activity students will be familiar with the wave nature of light. Then I will spend a day explaining that the electromagnetic spectrum that makes up the visible spectrum that they have completed studying is described in terms of a wavelength 400 – 700nm colors blue to red. On this day I will show them the visible spectrum and the wavelength. This will be a very traditional lecture type explanation, a water and pebble wave demonstration.

I found an activity in *Science Teacher* called glow in the dark science. This activity teaches both the wave and particle nature of light. This activity if used in a physics class could be used to teach students how to calculate the energy of light. I do not plan to teach students how to calculate but rather show them the effect that light has on electrons. In this activity three different light sources are to be used to excite the electrons of a glow in the dark star. Other glow in the dark materials could be used. The students will see that only light with a short wavelength will have enough energy to make the star glow. The longer wavelengths will not cause emission of light by the star regardless of the intensity or duration of the light. The students will see that when the electrons are excited, after they have absorbed sufficient energy the star will glow. The glowing is a result of the electrons being promoted to higher energy levels. It is not likely that the electrons will remain at the higher state, and the electrons will emit energy as it returns to the ground state. This energy is emitted in the visible region of the spectrum and can be seen by the human eye. When the electrons of a phosphorescent star return to the ground state the emitted photons glow. The glowing is observable is phosphorescence is due to the long lifetime of the electronic transition in the semi-conducting material within the polymer matrix of the star.

To begin the activity a bright flashlight, a handheld UV light source, and a red laser pointer, and glow in the dark stars are needed. All safety precautions are needed when using the UV light and using the pointer. I would do this activity as a demonstration, allowing the students to handle only the flashlights. This may vary from class to class as the maturity of the students is taken into consideration. I would then turn the lights out so that the students can see that none of the stars are glowing. Then I would shine the red laser on the star for thirty seconds. Then the student would be able to see that the star is not glowing. Next, the students would shine the flashlight on the stars, and then they will see the star glow when the light source has been removed. After the glowing has stopped, I would shine the UV light upon the stars and when the UV light has been taken away the students will see the star glowing. Obviously the lower energy needs to be first, red laser followed by the flashlight and lastly the UV light. Due to the variation of intensities of the light source students should report their finds as "glowing" or "not glowing."

At the end of this activity student can calculate the energy of the red light source a 670 nm, the flashlight source 500 nm and the UV source 254nm in approximation. Because I am not a physics teacher, I would not teach the actual equation, but I would have the students find the approximate wavelength on a chart and answer the following questions. Would an infrared light source cause the star to phosphoresce? Would a microwave source?

At this point I would make the connection between the plant absorbing energy in the chlorophyll within the leaves of green plants and activity. The student should recognize that a minimum amount of energy is needed to kick an electron to a higher energy level, and that in plants this energy is what is used to start the photosynthetic process.

After completing the glow in the dark activity, I would like my students to look at the visible spectrum and make some predictions about the type of light or wavelength under which green plants would grow best. Then I would have them design an experiment to investigate their predictions. I will provide them some plants that can be planted and exposed to different wavelengths of light. A class period would be devoted to a discussion around the "how" and the "why" of an experiment, discussing independent and dependent variable, and why they would be important. Data collection and the use of a journal to record information and thought during the experiments, and possible questions that arise during the experiment would need further investigation. Additional discussion would center on how the data would be collected, and the length of time the experiment would run. I would then put the students into groups of 3 – 4, and give them some additional time to create an experimental plan that needs to be submitted to me for review. After I receive such a plan from each student I will review and approve the plan. Then I will give them the supplies that they need to begin.

While the experiment is running, I will introduce to students how pigments either absorb or reflect light. The energy in the photons of light is responsible to excite the chlorophyll molecule by boosting the electrons of chlorophyll a higher energy level. The electron loses the excess energy and then falls back to its ground state almost immediately. Many things happen to the energy that is released in the process. Some energy may be released as heat; some pigments emit light as well as heat after absorbing photons. The sun powered electron transfer from chlorophyll to the electron acceptor is the first step in the light reactions and the first of many red-ox reactions in photosynthesis. The students will need to collect data from the plants daily. This is to be completed before class begins each day. Students may delegate the responsibility to record data to different group members. That will be up to the individual groups.

Research has demonstrated that students often miss the connection between photosynthesis and plant growth. I want them to see that plants use the ATP and the hydrogen from the light cycles to manufacture carbohydrates. I plan to assess my students' prior knowledge by asking two simple questions. "How do plants grow in size and mass?" "Where does the mass come from?" I will use these questions to introduce the Calvin cycle. To help my students focus around a question I will have several pieces of butcher- block paper or poster paper at each lab station with the questions written on the top. I will allow student groups 10 – 15 minutes to write how they think plants grow. At this point they have some idea that the plant captures light from the sun and converts it into a useful form of energy for living systems. After their brain storming secession, they will share their thoughts with the class. This set is similar to what research scientist do when they explore how they think phenomena occur. The scientist may have more background knowledge, but the processes of sharing information and discussing thought processes is an essential stage in designing experiments. It may also serve as a baseline so that the scientist or as in this case the students know what information they still need to acquire. After sufficient discussion, I will ask them what type of experiment we could set up to determine what is the most essential ingredient needed for plants to grow in mass. We would then make a list of ideas and discuss them as to whether or not they would be feasible. I will use this to engage them with the problem and then I will take them to the library so that they can research the history of the discovery of photosynthesis. I will have them research Joseph Priestly and his experiment as well as Ingenhausz's contribution to the understanding of photosynthesis, that light was required for photosynthesis to occur. He also showed that plants like animals respire. Another scientist Senebier, showed that plants use carbon dioxide when they produce oxygen. With this information, Ingenhousz was able to write an accurate general formula of photosynthesis in 1796.

After the students have had two class periods to research the history of photosynthesis, they will discuss their findings within their groups and create a list of words that they encountered in the various readings they did not know, whose meaning. After they have created the list they need to define the words and create their own definitions and then write a word that could be used in place of the word that they did not understand. After they have turned in this list they need to write an informational essay summarizing their findings. This will be assessed using the rubric obtained from PSSA

Classroom Connection web site. The content goal of this exercise is for the students to realize that $CO_2$ from the air is the same C that is contained in the glucose and other organic molecules produced by the plants.

The next day in the library I will have them research Melvin Calvin and his contribution to the current understandings of the photosynthetic process. They will be given a question that they will need to find the answer to, “What is the Calvin Cycle?” They will need to write the answer to the question in a notebook. I will informally assess the information. They will need to record any word that they encounter that they do not understand. I believe that this step is critical to the students’ overall language development so that they learn how to become an independent learner.

The next two days of lessons will be more traditional and lecture based helping the students put the big picture together. I will give them notes to summarize photosynthesis. The notes will explain how the light energy from the sun is trapped by the chlorophyll in the plants, how that energy is converted to ATP, and that H20 is split and the 02 is given off as waste and the H is transported to the Calvin cycle where the organic molecules are assembled by extracting the carbon from the CO2 from the atmosphere. During the lesson I will show a short clip of the Biology of the Standard Deviants. In this short video clip the entire process of photosynthesis is reviewed and explained in a humorous way.

As a conclusion activity each group will have to develop a summary report of all the work that they have completed. They must also include a formalized laboratory report for the experiment. The reports may take a number of different forms. Poster lab report is one example. This would be the format used at PJAS and other science fair competitions and exhibitions. The students would be encouraged to make transparencies of their finding so that they can communicate effectively with their peers. The students could present a power point presentation of their findings. The student could assemble a video tape presentation as a means to show their peers the research that they have concluded. A necessary component of the final report must include a variety of reasons to study photosynthesis.

By completing this unit, I hope that my students realize the importance of photosynthesis. I also hope that this experience helps them to become life-long learners of science, and of the scientific process. An additional goal for this unit is to help students prepare for the mandatory research project required for graduation in the state of Pennsylvania.

# Format for Writing a Lab Report

**Problem**: A statement telling what you are trying to find out

**Background:** A paragraph or two that contain pertinent information about the problem

**Hypothesis:** A statement that can be tested - explaining what you think will happen

**Materials:**

**Procedure:**

**Data Table:**

**Analysis:** This needs to include a graph. You also need to explain what happened and why

**Conclusion:** A paragraph stating the hypothesis and explaining whether it was supported or rejected by your data. How might the experiment be improved.

**Standards**

Pittsburgh Public School Science and Technology Standards

1. All students explain how scientific principles of chemical, physical and biological phenomena have developed and relate them to real-world situations.

2. All students demonstrate knowledge of basic concepts and principles of physical chemical, biological and earth sciences.

3. All students use and master materials, tool and processes of major technologies, which are applied in economical and civic life.

4. All students explain the relationships among science, technology and society.

5. All students construct and evaluate scientific and technological systems using model to explain or predict results.

6. All students develop and apply skills of observation, data collection, analysis pattern recognition, prediction and scientific reasoning in designing and conduction experiments and solving technological problems.

7. All students evaluate advantages, disadvantage and ethical implications associated with the impact of science and technology on current and future life.

8. All students evaluate the impact on current and future life of the development and use of varied energy forms, natural and synthetic materials, and production and processing of food and other agricultural products.

9. All students demonstrate basic computer literacy, including word processing, software application and the ability to access the global information infrastructure, using current technology.

**Annotated Bibliography/Resources**

Arms Karen and Pamela S. Camp. Biology. Holt, Rhinehart and Winston. New York. 1979.

This is an old book that had been used in the advanced biology classes in the Pittsburgh Public Schools. Although it is an older publication the information about the history of photosynthesis was very helpful.

ASK ERIC Lesson plan

This is a web site designed to help teachers expand ideas for lessons. It contains lessons on various topics. It can be very helpful to obtain new ideas for lessons or ways to enhance lesson/labs that a teacher has done for years.

BSCS Biology A Human Approach. Kendal Hunt.Dubuque. Iowa. 1997.

This text-book in an inquiry based text. It is the textbook that will be piloted in the school year 2002 – 2003 in the Pittsburgh Public Schools general biology.

Campbell. Mitchell. Reece. Biology concepts and Connection. Addison Wesley Longman, Inc. New York.2000.

This is a college level text that was used to acquire addition background information.

National Research Council. How People Learn. Bridging Research and Practice. National Academy Press. Washington, DC. 1999.

This book is bridge between research and practice. It is meant to be read by all educators so that student can receive instruction based on how people learn best.

National Research Council, National Committee on Science Education Standards and Assessment. (1994) National Science Education Standards. Washington, D.C: Author

This book explains the fundamentals if inquiry based instruction. It reflects the principles that learning science is an inquiry-based process, and all Americans have a role improving science education

Physics Today Revolution in Science Education: Put Physics First!
Wysiwyg://7/http://www.physicstoday.org/pt/vol-54/iss-9/p11.html

This article gives very sound arguments as to why high school students should study physics first.

The Science Teacher April 2002 Vol. 69 No.4

The National Science Teachers of America distribute this publication.  It contains timely discussion of topics relevant to teaching science in today's inquiry based classrooms.

How Stuff Works

This web site gives great explanations as to how things work.