Nanotechnology, Biological Engineering and the Future of Biosensors

Lesson Overview:
Nanotechnologies allow the digital world and the biological world to merge and can therefore detect biological substances. Such "hybrid technology" uses an analytical device to provide a digital signal when encountering specific concentrations of a targeted substance. The biological material can be from human tissues, microorganisms, organelles, cell receptors, enzymes, antibodies, or nucleic acids, as examples. Since these devices are detecting biological substances, they are known as biosensors. The synthetic side of biosensors uses optical, electrochemical, thermometric, or magnetic systems for sensing the designated biological substance. How prevalent will biosensors become in our lives? Already, "scientists are coming up with biosensors which when implanted in your body could even signal when you're getting sick - almost like the 'check engine' light in a car."

Unit question: Could biosensors[1] easily and safely monitor our health in the near future?

Learning Objectives:
- Develop a basic knowledge of nanotechnology as used to detect biological functions of the human body
- Investigate examples of biosensors as a type of nanotechnology
- Investigate processes for making and discovering uses for biosensors
- Analyze options and present to class ways to use biosensors to detect/monitor futuristic health care opportunities
- Demonstrate learning by "pitching" student-created nanotechnologies to investors so that they can build and test their own devices

Academic Standards:

National Science Education Standards

Matter, Energy, and Organization in Living Systems

- The complexity and organization of organisms accommodates the need for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.
- As matter and energy flow through different levels of organization of living systems-cells, organs, organisms, communities- and between

[1] A biosensor is a device that detects, records, and transmits information regarding a physiological change or the presence of various chemical or biological materials in the environment. More technically, a biosensor is a probe that integrates a biological component, such as a whole bacterium or a biological product (e.g., an enzyme or antibody) with an electronic component to yield a measurable signal.

living systems and the physical environment, chemical elements are recombined in different ways.

Science and Technology

- Implement a proposed solution
- Evaluate the solution and its consequences

Time Frame:
This lesson requires 3 – 5 classes of 45 minutes in length. This time line depends on the depth to wish the teacher wishes to expose students to human health conditions where biosensors may be relevant; the amount of time available for individual/group research on key topics; the extent to which the scientific method should be employed in the project conceptualization and design phase. Here, students will identify a problem and implement a proposed solution. Thus, the lesson can also serve as a model for actual scientific discovery and problem solving.

Background for the Teacher:
People often compare the human body to a machine, made up of systems that work together to keep it running. Like machines, though, pieces of the body can break down. This is where the exciting world of nanotechnology comes in. For example, one might look for the chemical signals in the body that warn of cancer, or refine robots that doctors are beginning to use in some surgery. In this unit, students will investigate nanotechnology by looking at hybrid technology between synthetic and biological materials. Specifically, these biosensors can be used to help improve an individual's health or health care.

Materials for the teacher:

- LCD projector for viewing lesson activities
- Access to computer lab and/or media center
- Supplemental text books dealing with human biology, health, and modern medical approaches
- Supplemental text books or media center access for students to explore meanings and examples of nanotechnologies
- Poster board and markers for students
- PowerPoint access
- Classroom suitable to break-out groupings of various sizes, and ability for student presentations using LCD projector or poster board

Materials for each group of students:

- Art materials including poster board, backboards, colored pens, scissors, glue, and tape
- Access to all print-outs from this lesson included in Appendices
- Access to text books, computers and other resources for individual/group research
- Common background knowledge of human biology and disease
- AP biology useful, or other advanced biological science
- Folder or notebook in which all student information can be kept, to be turned in at end of lesson as a portfolio

Classroom Activities:

Engage

1. What does the term "hybrid" technology mean? Students explore this question using the new generation of hybrid cars as a starting point, being as detailed as possible. Teachers can use "think – pair – share" to get things started. Let students think about this question individually while jotting down their ideas. Then, encourage them to brainstorm ideas in pairs, before moving to small groups. Use a capture sheet for each student to record his or her group's input. Once in groups, ask that they also:
    - Consider the pros and cons of the technology
    - Understand how electrical and petroleum fuels are generated/used
    - Provide an estimate of the year this technology put hybrid cars on the road

    Then, ask a student to go to the front of room and facilitate a discussion among the groups to gather class-wide answers to the questions. The class should then come up with a common definition and understanding of hybrid technology.

2. Let students log onto the following URL for an animated, interactive video on nanotechnology and the life sciences. Encourage them to explore the video, and jot down three items they wish to learn more about, using an organizer.
    Amazing Creatures with Nanoscale Features:
    http://www.cneu.psu.edu/activities/Amy/index.html

3. What does it mean to work at the "nano" scale? Let students refresh their memories of the metric system of measurement, beginning with the meter. Have meter sticks available, or smaller rulers showing the millimeter. Ask students if they know what comes after the millimeter, then, how small a Nanoscale measurement must be.

    Following discussion, have the figure from **Appendix 3** ready to project on screen. Ask students to take out a sheet of paper and put a line at bottom showing a scale from smallest to largest. Then, ask them to put the following objects in order of size, from smallest to largest: hair, bacterial cell, dust particle, carbon atom, DNA helix, computer chip wire, and a red blood cell. Once done, show them the figure on the screen and discuss the answers. Explain that the "Nanoscale" is measured in nanometers, or billionths of a meter.

    Now, let's consider how nanotechnologies, such as biosensors, are made.

Explore

A graphic organizer found in Appendix 1 is provided to help students consolidate their knowledge on the first four activities and readings below. A separate organizer is used for Activity Five below.

1. What is meant by nanotechnology? Students will explore what it means to manipulate and manufacture materials on the scale of atoms or small groups of atoms. For this reading and summation, students work in groups of two or four. After reading, students

discuss nanotechnology to build understanding. Then, the teacher can go around the room, collecting key ideas from each group and writing on the whiteboard. Students can compare these collected comments with what they have in their notes in the Organizer.

2. Provide students with the following article, Bacterial Bioluminescent Biosensors: http://science.howstuffworks.com/environmental/green-science/color-coded-bacteria1.htm. Using this article, students will consider how biosensors work (as one example of nanotechnology), how matter and energy are detected, and finally, how it is reported to the user. They can investigate biosensors and how they aid spotting oil spills. The article has several other links students can explore. Finally, students can consider what type of use such biosensors could fulfill in the near future. Students capture this information in Appendix 1.

3. Students will explore the role that 'Smart Fabrics' can play as biosensors. They will use the reading, *'Smart' Materials:* http://www.bbc.co.uk/schools/gcsebitesize/science/edexcel/designerproducts/smartmaterialsrev1.shtml

   In their notes, students should consider what advantages/disadvantages such smart fabrics would have. For what type of conditions would such fabrics be useful? Do they sound feasible, or more like science fiction? Again, allow students to work in groups, sharing freely in a class discussion once done. A student can lead a discussion and do the summarizing, modeling the teacher's role for the reading above. Answers go into Appendix 1 organizer.

4. Students will explore the link, *How Nanotechnology Works*: http://science.howstuffworks.com/nanotechnology.htm. This also provides a video on nanotechnology. Next, the future of nanotechnologies is considered through the link: http://science.howstuffworks.com/nanotechnology4.htm. Students consider three to five areas in which the author predicts nano breakthroughs. Which of these seem to be the most feasible in the near-term future? Why? Next, students are organized in groups around the five future areas. In their group, they develop arguments as to why their nanotechnology would be the most important one to have in the near-term future.

   Their notes are collected on a separate sheet of paper, and a spokesperson is elected to "argue" the relevance and priority of their nanotechnology in front of the class. Alternatively, to ensure each technology is represented, the teacher can assign the five future uses of nanotechnologies to pre-selected groups. This would prevent the class from all picking one or two of the most exciting nano opportunities. Finally, student and group notes are continued under the section "explain" below.

5. Hands on activity: Building a Biosensor.
   Students will use the web link, *Biosensors and Other Medical and Environmental Probes,* http://www.ornl.gov/info/ornlreview/rev29_3/text/biosens.htm, from the Oak Ridge

National Laboratory. It presents various options for using various types of bio nanotechnologies. Appendix 4 lists some of these examples for student selection.

Using construction paper, markers, and labels, students will work in a group to build a working model of the particular bio nanotechnology of their choice. The articles above provide background to build their understanding of the hands-on work. After reading all articles, students again work in groups to pick a human health problem and implement a proposed solution using biosensors. Appendix 2 contains a graphic and text organizer to be used for this activity. Students will consider whether the bio nanotechnology is already developed, or is something they would need to invent.

Once the bio decision is made, students can develop the type of biosensor needed to monitor or detect the substance of interest. Students can decide if they wish to implant the device or use an externally located system. They will then evaluate their solution and its consequences, looking in particular as to whether or not it is better than technologies available.

To make the model biosensor, students cut out pieces of the bio nanotechnology, describe how it can be used to detect a human disorder, and show how it will work by affixing the parts to a poster backboard. They will describe how the sensor works and what happens to the bio nanotechnology they have chosen. In other words, whether it fluoresces, turns color, or creates an electrical signal.

6. Optional side concepts to include in this lesson:
    - Use of the scientific method in problem solving, identifying a problem, assessing options for its solution, implementing the solution and testing. This will serve as good background for latter parts of this activity when students break into groups for nanotechnology product development. This can include an explanation of research venture funding, as well as marketing an idea, as students will also be asked to pursue these topics.

Explain

1. Following from research done above, students prepare presentations for the class. First, students prepare a poster or PowerPoint presentation from their group work, choosing the most important, near-term technology from Activity 4 above. Then, the elected spokesperson comes to the front of the class, where he/she tries to persuade the class on the importance and relevance of the technology the group had selected.
2. A second presentation focuses on Activity 5 above, where students select a human health care need and imagine how it would be addressed through biosensors. A poster or PowerPoint is made for this presentation. However, before that begins, the teacher divides the class in half. One group will be participants representing each of the five technologies. The second group will represent five different investment banking firms. First, students from the first group make marketing presentations for their selected medical nanotechnology, or biosensors.

Second, after those presentations are concluded, the group of investment bankers selects one or more of the technologies for investment and explains why they selected the technologies they did. The group of technology developers receiving the most overall investment funds is awarded "best nanotechnology product for the year."

Extend

1. A. Students consider how another hybrid technology, specifically the use of antibody-antigen reactions for influenza detection, can be useful to modern health care. For this activity, students consider a rapid biosensor/bioassay test using 3M™ Rapid Detection Flu A+B Test. Students read a product description and watch a video showing how such rapid detection works. The link is: 3M™ Rapid Detection Flu A+B Test, at URL below:

   http://solutions.3m.com/wps/portal/3M/en_US/infection-prevention-solutions/home/products/?PC_7_RJH9U52308DUB0IIL8TMGN3013_nid=P0QW4DBRMRbeH2P77K2B0Hgl

   The demo video is found on that page, 3M Rapid Detection Flu A+B Test Demo Video.

1. B. After reading about this influenza biosensor, students list five ways in which it demonstrates the use of biological and information technologies, how it represents a hybrid technology, and how it is similar to the other technologies in this lesson.

1. C. Have students investigate Influenza, strains A and B. Let them search for alternative means of detection. Why do they think 3M™ developed this particular product? Is it competing with others, or is it the only one of its type? Such questions amplify student understanding of the scientific method, research, and development of new technologies.

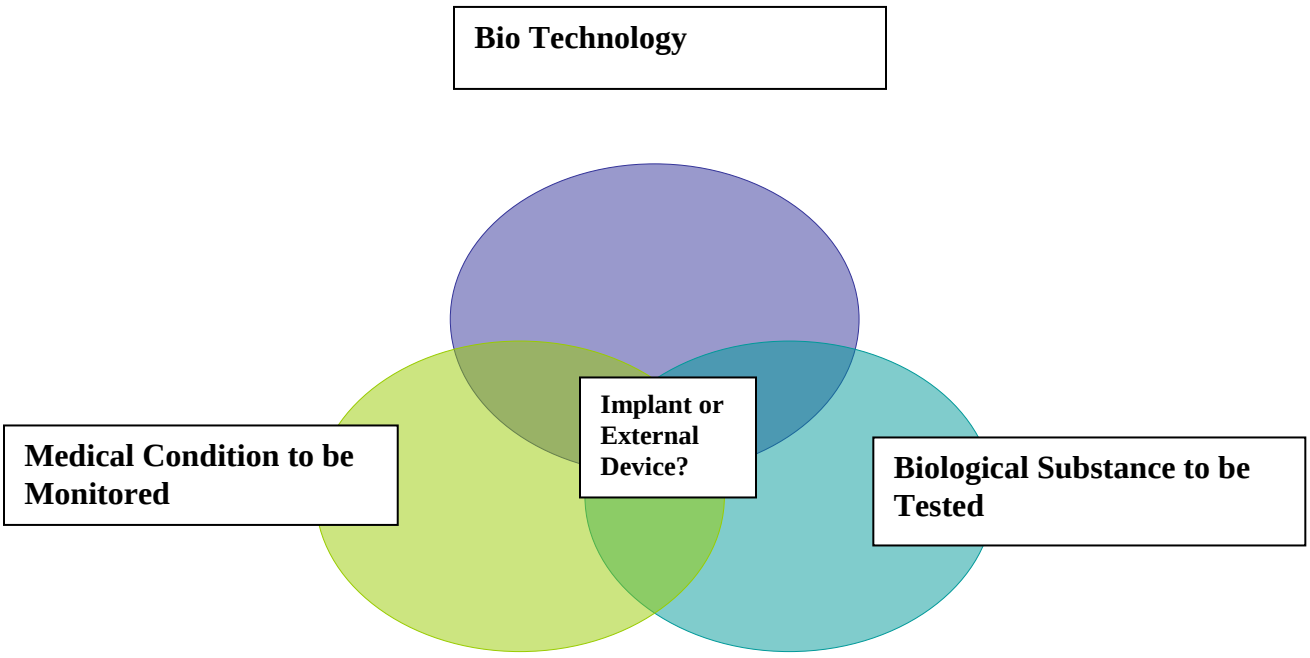
Evaluate

1. Student workbooks or portfolios are submitted for grading as a formative assessment on hybrid technologies, which should include all student work for this lesson.
2. Venn diagram completed to compare and contrast options for the use of nanotechnology and hybrid technologies
3. Essay on the use of biosensors in human health applications
4. Poster advertising future uses of nanotechnologies and directions for its research

Appendix 1. Graphic Organizer for Readings on Nanotechnology

Reading	Individual/Group Notes	Class Notes
What is meant by nanotechnology?		
Biosensors on the Fast Track:		
'Smart' Fabrics Integrate Biosensors to Monitor Respiration Rate and Body Temperature in Real Time		
Nanotechnology: It's a Small, Small, Small, Small World,		

Appendix 2. Graphic Organizer for Use with Article, "Biosensors on the Fast Track"



1. Imagine that you are part of the Medical Device Innovation Initiative. You have been challenged by the Food and Drug Administration of the US government to come up with a new biosensor that can be pilot-tested in this Initiative. Your tasks are threefold:
   i. Find a medical condition that needs monitoring (one that patients or consumers consider helpful and essential)
   ii. Design or locate a suitable biomarker that can be detected through a biosensor
   iii. Using nanotechnology, develop the technology needed to monitor this biomarker

   Once done, decide if it would be best to implant the device or conduct tests (For example, periodically checking blood).

   In order to substantiate your choice, research human health needs and then select any condition you wish. Good questions to consider include, what are mortality figures stemming from the condition? What happens if the condition remains untreated or is not monitored?

Then, decide on a suitable biomarker, or allow for the creation of such by your team. Finally, what would the biosensor technology look like for its detection? What type of nanotechnologies would be employed in its development? Once done, decide if it should be implanted or worn/used externally.

2. Your selections:

   A. Human health condition: _____

   B. Justification for its selection:
   _____
   _____
   _____
   _____
   _____

   C. Specific biological material related to the condition for testing:
   _____

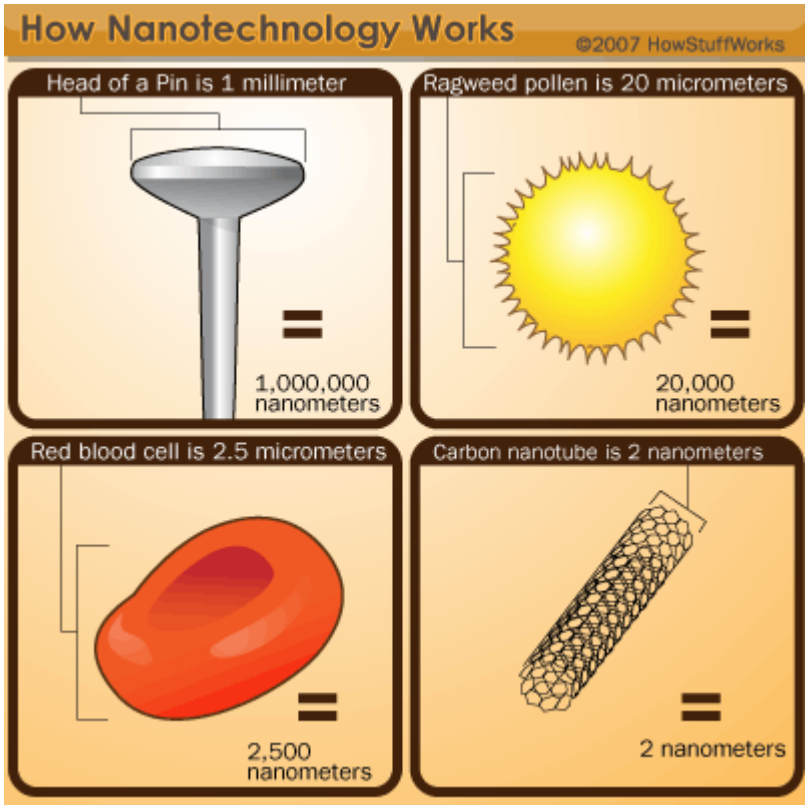
   D. How is this material examined?
   _____
   _____
   _____

   E. What steps involve using nanotechnologies to assemble a biosensor for that material?
   _____
   _____
   _____
   _____
   _____

   F. Finally, is the device best used as an implant, or monitored through external testing? Justify your answer.
   _____
   _____
   _____
   _____

   G. Is your bio nanotechnology invention better than what currently exits to help monitor or control the condition you have selected? Please explain.
   _____
   _____
   _____
   _____
   _____

Appendix 3. How Small Is A Nano?



Appendix 4. List of Bio Nanotechnologies for Modeling by Students.

Biosensors and Other Nanotechnologies	Goal	Example Applications
1. Medical Telesensors	To develop an array of nano chips to monitor bodily functions	• Blood pressure • Pulse rate • Diabetes
2. Cancer Detection	To develop biosensors that detect specific abnormalities in a living organism	• Optical bioassay sensor • Light detection of diabetes
3. DNA Analysis	To develop detection mechanisms for various organisms using DNA	• DNA processing and analysis chips
4. Miniaturized Devices	To develop nanotechnologies that turn a biological system into a tiny electronic device	• Blood chemistry analysis