Collecting Data for the NanoSense Evaluation

Thank you for choosing to use NanoSense materials in your class and helping us collect data about student learning. We are asking you to do four things in this effort:

1. Give a brief Content Quiz before and after the unit/lesson
2. Give a brief Science Attitude Survey before and after the unit/lesson
3. Have students fill out "Aha!" and Confusion Cards during the unit/lesson
4. Share a brief reflection with us on the lesson

A brief description of each follows, and all the materials you'll need are included in this packet. Completed materials (quizzes, survey, cards, your reflection) can be mailed to:

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SRI International
333 Ravenswood Ave., BN384
Menlo Park, CA 94025

Email: patricia.schank@sri.com
Phone: 650-859-3934

We'll reimburse any mailing costs and provide a thank-you gift for each complete packet (with items 1-4 above) that you send us. It's not required, but if you're nearby and open to letting us observe your lesson(s) with NanoSense, let us know. Please don't hesitate to contact us if you have any questions!

1. Content Quizzes (10-15 minutes, before/after unit/lesson)

These quizzes are short (e.g., 4-6 question) tests of student knowledge about concepts covered in the NanoSense materials. Each NanoSense unit (Size Matters, Clear Sunscreen, Clean Energy, Fine Filters) has an associated content quiz. Give the quiz twice: once before you start any lessons from a unit, and once after you have completed all lessons that you plan to do in that unit. Note that you don't have to use all materials from a unit to give the quizzes, but do let us know what lessons you did (see #4 below). Also, let students know that it is okay if they don't know the answers; we just want to see what they know and what they learned.

2. Science Attitude Surveys (5 minutes, before/after unit/lesson)

This brief survey assesses changes in student attitudes toward science, to see if learning about a new area of science—nanoscience—affects student attitudes about science (interest, relevance to daily life, etc.). Give this survey at the same time that you give a content quiz.

3. "Aha" and "Confusion" Cards (during lesson)

The cards are useful to capture student thoughts "in the moment" to see what they find interesting or difficult. They can also help you tailor the class to address student confusions.

At the beginning of class, hand out two colors of index cards to your students. One color is for them to write down things they find confusing or have questions about during the lesson(s). The second color is for them to capture and share "light bulb" or "aha" moments. Let students know they can fill out the cards at any point during class and that they do not need to put their name on the cards. At some point during the lesson (at the end of each class works well for multi-class lessons), collect the cards. You can use the cards to share student "ahas" and address confusions. Please hold onto the cards and give them to us when you are done with the lesson.

(over)

4. Reflections on the Lesson (15 minutes, after unit/lesson)

After completing the unit/lesson, please answer the following questions. You can email your answers to us or include this page in the materials that you mail to us. Feel free to use additional sheets if needed. Also, if you created a written lesson plan, you may attach and refer to that in your answers.

Name: ________________________________ Email: ___________________________________

School: ____________________________________ Grade & Subject: ______________________

1. What activities did you use with your class? Please be specific not only about the unit / lesson(s) you did, but also the specific materials (e.g. PPT, teacher notes, student reading, lab activity etc.)

2. Did you change or modify the materials in any way to fit your classroom's needs? If so, how?

3. For how many class periods was the unit/lesson implemented? Was any homework given between classes? If so, what?

4. How did the lesson go?

    - Did students seem to be interested in the lesson?

    - Did they seem to understand the content?

    - Were there any areas of confusion?

Name__________________________________ Date______________________ Period ______

Thoughts about Science: Presurvey

For each statement below, please check the ONE response that most closely reflects your view.

1. Much of what I learn in science classes is useful in my everyday life today.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

2. Science helps me to make decisions that could affect my body.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

3. Science will help me understand more about world-wide problems.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

4. Science can help me to make better choices about various things in my life (e.g., food to eat, car to buy).

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

5. Understanding science helps me explain things better to others.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

6. I am interested in a career as a scientist or engineer.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

7. Please comment on any of these issues in your own words.

For each question below, please check ALL the responses that you think apply.

8. Why don’t we fully understand how nanoparticles behave?

__we haven’t run enough experiments

__current tools don’t have enough precision

__nanoparticles don’t behave predictably

__current scientific models don’t explain nanoparticle behavior adequately

__it is not possible to fully understand behavior at the nanoscale

9. Why is there a lot of buzz about nanoscience right now?

__it’s a new field of science that’s just been discovered

__many companies are incorporating nanoparticles into their products

__new technologies allow us to better “see” and manipulate at the nanoscale

__nanoscience applications could help address major world problems

__they give us improved products without new health risks

For each question below, please write a short response of a few sentences.

10. Why do our scientific models change over time?

11. Do we need to fully understand the properties of nanoparticles in order to create useful materials out of them? Explain your answer.

Name________________________________ Date_____________________ Period ______

Thoughts about Science: Postsurvey

For each statement below, please check the ONE response that most closely reflects your view.

1. Much of what I learn in science classes is useful in my everyday life today.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

2. Science helps me to make decisions that could affect my body.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

3. Science will help me understand more about world-wide problems.

__ strongly agree
__ somewhat agree
__ neutral
__ somewhat disagree
__ strongly disagree
__ don't understand the question

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__ neutral
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__ strongly disagree
__ don't understand the question

5. Understanding science helps me explain things better to others.

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__ strongly disagree
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6. I am interested in a career as a scientist or engineer.

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__ somewhat disagree
__ strongly disagree
__ don't understand the question

7. Please comment on any of these issues in your own words.

For each question below, please check ALL the responses that you think apply.

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For each question below, please write a short response of a few sentences.

10. Why do our scientific models change over time?

11. Do we need to fully understand the properties of nanoparticles in order to create useful materials out of them? Explain your answer.

Name_________________________________ Date_____________________ Period ______

Size Matters: Pretest

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye.

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example.

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale.

4. What do we mean when we talk about “seeing” at the nanoscale?

5. Choose one technology for seeing at the nanoscale and briefly explain how it works.

6. Describe one application (or potential application) of nanoscience and its possible effects on society.

Name_________________________________ Date______________________ Period ______

Size Matters: Posttest

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye.

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example.

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4. What do we mean when we talk about “seeing” at the nanoscale?

5. Choose one technology for seeing at the nanoscale and briefly explain how it works.

6. Describe one application (or potential application) of nanoscience and its possible effects on society.

Size Matters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. How big is a nanometer compared to a meter? List one object that is nanosized, one that is smaller, and one that is larger but still not visible to the naked eye. (1 point each, total of 4 points)

A nanometer is one billionth of a meter (or 10^{-9} m in scientific notation).

Sample nanosized objects:

- Virus, DNA strand (diameter), Ribosome, Hemoglobin, Sucrose molecule
- Carbon nanotube (diameter), Buckyballs
- Some enzymes (e.g. ATP synthase), some "molecular motors" (e.g. kinesin)
- Photosynthetic machinery in plants and bacteria,

Sample objects that are smaller:

- Water molecule
- Atoms
- Sub-atomic particles (protons, neutrons, electrons)

Sample objects that are larger than but still not visible to the naked eye:

- Bacteria, Ameoba
- Human egg cell, Human sperm cell
- Red blood cell

2. Name two properties that can differ for nanosized objects and much larger objects of the same substance. For each property, give a specific example. (2 points each, total of 4 points)

Optical properties (such as color and transparency):

- Bulk gold appears yellow in color, nanosized gold appears red in color.
- Regular zinc oxide appear white on the skin, the nano-version appears clear.

Electrical properties (such as conductivity):

- Carbon nanotubes conductivity change with diameter, "twist," and number of walls.
- Physical properties (such as density and boiling point).
- Nanoparticles have lower melting and boiling points b/c there is a greater percentage of atoms at the surface (require less energy to overcome intermolecular attractions).

Chemical properties (such as reactivities and reaction rates):

- Nanoparticles have a greater percentage of atoms at the surface and thus greater reactivities (students may mention any of the examples of this done in the labs).

3. Describe two reasons why properties of nanosized objects are sometimes different than those of the same substance at the bulk scale. (2 points each, 4 points total)

Dominance of electromagnetic forces:

- Gravitational force is a function of mass and distance and is weak between (low-mass) nanosized particles.
- Electromagnetic force is a function of charge and distance is not affected by mass, so it can be very strong even when we have nanosized particles.

Quantum effects:

- At very small scale, the classical mechanical models that we use to understand matter at the macroscale don't work.
- The quantum mechanical model that does help us understand matter is based on probability, not certainty and unusual results such as quantum tunneling (when an electron can "pass through" an energy barrier) may occur.

Surface to volume ratio:

- As surface area to volume ratio increases, a greater amount of a substance comes in contact with surrounding material, this increase reaction rates.

Random molecular motion:

- While random molecular motion (molecules moving around in space, rotating around their bonds, and vibrating along their bonds) is present for all particles, at the macroscale this motion is very small compared to the sizes of the objects and thus is not very influential in how object behave.
- At the nanoscale however, these motions can be on the same scale as the size of the particles and thus have an important influence on how particles behave.

4. What do we mean when we talk about "seeing" at the nanoscale? (2 points)

- "Seeing" an object means using a tool that interacts with the object to produce some representation of it (often an image).
- While many common tools use the interaction between visible light and an object to create a representation, at the nanoscale the objects we want to "see" are smaller than the wavelengths of visible light so this approach is not useful.
- To "see" at the nanoscale, we need to use tools that leverage other kinds of interactions with the surface of the object (like electrical and magnetic forces) to create a representation of the object.

5. Choose one technology for seeing at the nanoscale and briefly explain how it works. (3 points)

Atomic Force Microscope (AFM)

- Uses a tiny tip that moves in response to the electromagnetic forces between the atoms of the surface and the tip.
- Either measures the tiny upward and downward movement of the tip necessary to remain in close contact with the surface or makes the tip vibrate to tap the surface and senses when contacts is made.
- In both bases, the signals (forces or contact) change based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object.

Scanning Tunneling Microscope (STM)

- Uses a fine tip that can conduct electricity; the nano-object to be imaged must also conduct electricity.
- The tip is put very near, but not touching the object surface and the "tunneling" of electrons between the tip and the atoms of the object's surface being creates a flow of electrons (a current).
- The signals (current) changes based on the features of the object's surface (height, angle etc.) and are used to infer a topographical image of the object.

6. Describe one application (or potential application) of nanoscience and its possible effects on society. (3 points)

Existing Applications Include:

- Stain Resistant Clothes: Fine-spun fibers ("nanowhiskers") are embedded into fabrics and act like peach fuzz to create a cushion of air around the fabric so that liquids bead up and roll off. This innovation will leads to less stains, less need for washing clothes (using detergent) and dry cleaning (using chemicals), and even less need to replace (and thus produce clothing). These could all have positive impacts on the environment.
- Nano Solar Cells: Traditional solar cells provide one source of clean energy but they are expensive to produce. A new kind of solar cells use nanoparticles of TiO_2 coated with dye molecules to capture the energy of visible light and convert it into electricity. These solar cells are less expensive to produce and have the potential to be used in a wide range of applications.
- Clear Sunscreen: Traditional inorganic sunscreens (ZnO and TiO_2) provide powerful protection from the full range of UV light, but are often not used or under-applied because they appear white on the skin (due to the scattering of visible light). ZnO and TiO_2 nanoparticles provide the same UV protection as their larger counterparts, but are so small that they don't scatter visible light and thus appear clear on the skin.

Existing Applications (continued)

- Building Smaller Devices and Chips: A technique called nanolithography lets us create much smaller devices than current approaches. This technique can be used to further miniaturize the electrical components of microchips. Dip pen nanolithography is a 'direct write' technique that uses an AFM to create patterns and to duplicate images. "Ink" is laid down atom by atom on a surface, through a solvent—often water.
- Health Monitoring: Several nano-devices are being developed to keep track of daily changes in patients' glucose and cholesterol levels, aiding in the monitoring and management of diabetes and high cholesterol for better health. For example, some researchers have created coated nanotubes in a way that will fluoresce in the presence of glucose. Inserted into human tissue, these nanotubes can be excited with a laser pointer and provide real-time monitoring of blood glucose level.

Potential Applications Include:

- Paint That Cleans the Air: A titanic-oxide-based compound in nanosized particles has been claimed to clean the air by decomposing the major ingredients that cause air pollution such as formaldehyde and nitride. This compound could be used in paints, acting as a permanent air purifier and helping to improve the air quality in polluted areas.
- "Paint-On" Solar Cells: Scientists are trying to develop a photovoltaic material using semiconducting nanorods that can be spread like plastic wrap or paint. These nano solar cells could be integrated with other building materials, and offer the promise of cheap production costs that could finally make solar power a widely used electricity alternative.
- Drug Delivery Systems: Nanotubes and buckyballs could serve as drug delivery systems. Because they are inert and small enough to cross many membranes, including the blood-brain barrier, they could be used to carry reactive drugs to the right part of the body and "deliver" the drug inside the appropriate cell.
- Water Treatment: Advanced nanomembranes could be used for water purification, desalination, and detoxification, nanosensors could detect contaminants and pathogens, and nanoparticles could degrade water pollutants and make salt water and even sewage water easily converted into usable, drinkable water. This could help address water crises across the plant.
- Clean Energy: Hydrogen fuel is currently expensive to make, but with catalysts made from nanoclusters, it may be possible to generate hydrogen from water by photocatalytic reactions. Novel hydrogen storage systems could be based on carbon nanotubes and other lightweight nanomaterials, nanocatalysts could be used for hydrogen generation, and nanotubes could be used for energy transport.
- Detecting Disease with Quantum Dots: Quantum dots are small cadmium-based devices that contain a tiny droplet of free electrons, and emit photons when submitted to ultraviolet (UV) light. Scientists are exploring ways to seal the dots in polymer capsules to protect the body from cadmium exposure; the surface of each capsule can then be designed to attach to different harmful molecules (for example those indicating presence of cancer). As the dots collect in a tumor, they become visible in ultraviolet light under a microscope, allowing doctors to identify and locate cancer earlier.

Name_______________________________ Date____________________ Period ______

Clear Sunscreen: Pretest

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how.

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has "nano" ingredients?

Name________________________________ Date_____________________ Period ______

Clear Sunscreen: Posttest

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how.

	Organic Ingredients (e.g. PABA)	Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)
Chemical Structure	Similar or Different How:	Similar or Different How:
Kinds of Light Blocked	Similar or Different How:	Similar or Different How:
Way Light is Blocked	Similar or Different How:	Similar or Different How:
Appearance on the Skin	Similar or Different How:	Similar or Different How:

2. Briefly describe one benefit and one drawback of using a sunscreen that contains “nano” ingredients.

3. What determines if a sunscreen appears white or clear on your skin?

4. How do you know if a sunscreen has “nano” ingredients?

Clear Sunscreen Pretest/Posttest: Teacher Answer Sheet

20 points total

1. In what ways are "nano" sunscreen ingredients similar and different from other ingredients currently used in sunscreens? For each of the four categories below, indicate whether "nano" sunscreen ingredients are "similar" or "different" to organic and inorganic ingredients and explain how. (1.5 points each, total of 12 points)

	Organic Ingredients (e.g. PABA)	**Inorganic Ingredients (e.g. Classic Zinc Oxide used by lifeguards)**
Chemical Structure	Similar or [Different] How: Nano ingredients are small ionic clusters while organic ingredients are molecules.	[Similar] or Different How: Nano ingredients are a kind of inorganic ingredients. Bother are ionic clusters but the nano clusters are smaller.
Kinds of Light Blocked	Similar or [Different] How: Organic ingredients each block a small part of the UV spectrum (generally UVB) while nano ingredients block almost the whole thing,	[Similar] or Different How: Both nano ingredients and traditional inorganic ingredients block almost the whole UV spectrum.
Way Light is Blocked	[Similar] or Different How: Both nano and organic ingredients block UV light via absorption. (The specific absorption mechanism is different, but students are not expected to report this)	[Similar] or Different How: Both nano and inorganic ingredients block UV light via absorption.
Appearance on the Skin	[Similar] or Different How: Both nano and organic ingredients appear clear on the skin.	Similar or [Different] How: Traditional inorganic ingredients appear white on the skin while nano ingredients appear clear.

2. Briefly describe one benefit and one drawback of using a sunscreen that contains "nano" ingredients: (1 point each, a total of 2 points)

Benefits:

- Block whole UV spectrum
- Appear clear, people less likely to underapply

Drawbacks:

- New chemicals not fully studied; possible harmful effects still unknown. FDA is not treating nano-versions of known chemicals as new; needed health studies may not occur.
- Very small particles are more likely to cross membranes and get into unintended parts of the body

3. What determines if a sunscreen appears white or clear on your skin? (4 points)

Answer:

- Particle size.

Explanation:

- Particles whose diameters are ≈ ½ λ are most likely to scatter light of that wavelength.
- Since visible light has λ ≈ 400-800 nm, particles with a diameter of 200-400 nm (traditional inorganic ingredients) scatter visible light the most. The scattered rays that are reflected towards our eyes are of all colors in the spectrum, making the sunscreen appear white.
- Particles smaller than 100 nm in diameter (nano and organic ingredients) do not scatter light appreciably. The sunlight passes through them and reaches our skin where the blue/green wavelengths are absorbed. The red/orange/yellow wavelengths are reflected towards our eyes making the skin appear its characteristic color.

4. How do you know if a sunscreen has "nano" ingredients? (2 points)

Ingredients list contains inorganic ingredients (zinc oxide or titanium dioxide) <u>and</u> sunscreen appears clear on the skin.

Name__________________________________ Date______________________ Period ______

Clean Energy - Pretest

1. List two advantages that nano-based, dye-sensitized solar cells can provide to address global energy issues.

2. Why is it important that the titanium dioxide particles used in dye-sensitized solar cells be very small (aka "nano")?

3. Explain what you know about dye-sensitized solar cells. Include an annotated diagram showing how they work.

4. What is the role of dye in a dye-sensitized solar cell?

Name______________________________ Date____________________ Period ______

Clean Energy - Posttest

1. List two advantages that nano-based, dye-sensitized solar cells can provide to address global energy issues.

2. Why is it important that the titanium dioxide particles used in dye-sensitized solar cells be very small (aka “nano”)?

3. Explain what you know about dye-sensitized solar cells. Include an annotated diagram showing how they work.

4. What is the role of dye in a dye-sensitized solar cell?

Clean Energy Pretest/Posttest: Teacher Answer Sheet

20 points total

1. List two advantages that nano-based, dye-sensitized solar cells can provide to address global energy issues. (2 points each, total of 4 points)

Possible answers include:

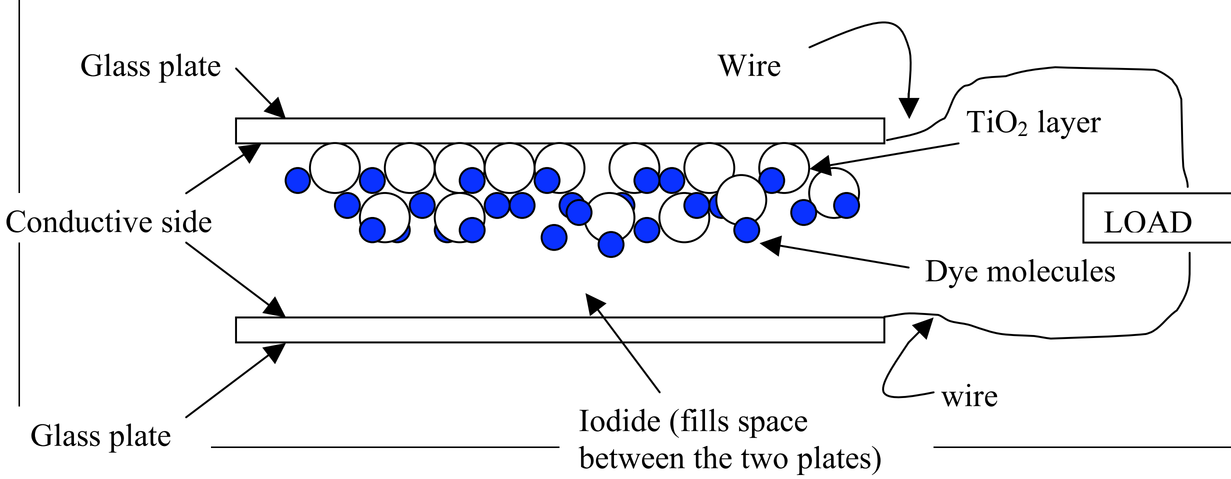
- Reduced pollution from the decrease in burning of fossil fuels (greenhouse gases, global warming, acid rain). Partial credit for associated issues (e.g. respiratory problems due to polluted air)
- Reduced dependency on fossil fuels (limited supply, bad for environment)
- Greater awareness of nanotechnology being used in positive ways to reduce our impact on the environment.
- Increased "economies of scale" – the more that nano-solar cells are used, the more they will be used in the future due to decreased manufacturing costs.
- Greater public acceptance and/or changing how people think about energy (conservation, "unlimited" supply, impact on environment)

2. Explain what you know about dye-sensitized solar cells, including an annotated diagram showing how they work. (6 points total)

Student should provide an explanation that hits on the following steps:

- light energy is absorbed
- electrons are released by the dye molecules (with positive "holes" left behind)
- electrons are infused into the TiO_2 and transported out of the cell
- the flow of electrons forms a current that drives a load
- electrons go back onto cell and are transported via the iodide solution back to the positive holes in the dye molecules.

Student should draw an annotated diagram similar in principle to the one below:



3. Why is it important that the titanium dioxide particles used in dye-sensitized solar cells be very small (aka “nano”)? (6 points total)

The TiO_2 particles are very small – 10nm to 30 nm. These are coated with the dye molecules and stacked so that there are effectively many “layers” of dye molecules that can potentially absorb light. The TiO_2 is invisible to the light waves in the range that the dye molecules absorb the bulk of the light (400nm-900nm), which makes it so the light can pass right through them and can be available for the dye molecules. By using nano-sized TiO_2 particles, the **high surface to volume ratio** allows for a large surface area for the dye molecules to be spread across, thus increasing the probability of light being absorbed by the dye molecules.

4. What is the role of dye in a dye-sensitized solar cell? (4 points total)

The dye molecules absorb light energy and release electrons. The dye molecules sit on top of the TiO_2 particles. When an electron is released from the dye, it moves into the conduction band of the TiO_2.

Name_________________________________ Date_____________________ Period ______

Fine Filters: Pretest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	**Is a nanomembrane the best way to filter it out?**
Bacteria	Yes or No	Yes or No
	Why/why not:	
Lead (Pb^{2+})	Yes or No	Yes or No
	Why/why not:	
Salt (Na^+ and Cl^-)	Yes or No	Yes or No
	Why/why not:	
Sand	Yes or No	Yes or No
	Why/why not:	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

Name________________________________ Date_____________________ Period ______

Fine Filters: Posttest

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	**Is a nanomembrane the best way to filter it out?**
Bacteria	Yes or No	Yes or No
	Why/why not:	
Lead (Pb^{2+})	Yes or No	Yes or No
	Why/why not:	
Salt (Na^{+} and Cl^{-})	Yes or No	Yes or No
	Why/why not:	
Sand	Yes or No	Yes or No
	Why/why not:	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

Fine Filters Pretest/Posttest: Teacher Answer Sheet

20 points total

1. Which of the following types of contaminants can nanomembranes filter out of water? For which of these, would you typically use a nanomembrane for removal? Explain why or why not. (1 point each, total of 12 points)

	Can a nanomembrane filter it out?	Is a nanomembrane the best way to filter it out?
Bacteria	[Yes] or No	Yes or [No]
	Why/why not: Bacteria are large enough that micromembranes can also filter them out of water. Micromembranes are less expensive to use and the large bacteria would quickly foul the nanomembrane.	
Lead (Pb^{2+})	[Yes] or No	[Yes] or No
	Why/why not: Divalent ions (such as lead) are too small to be separated out by micro- or ultra-filtration. Nanofiltration can remove them from water and is less expense than reverse osmosis (which would also remove them).	
Salt (Na^{+} and Cl^{-})	Yes or [No]	Yes or [No]
	Why/why not: Monovalent ions are too small to be filtered out by current nanomembranes. Reverse osmosis must be used.	
Sand	[Yes] or No	Yes or [No]
	Why/why not: Sand is large enough that it can be filtered by a simple mesh cloth. This is less expensive to use and the sand would quickly foul the nanomembrane.	

2. Name two benefits that nanomembranes bring to the filtration of water that help to address the world's problem of a scarcity of clean drinking water. (1 point each, 2 points total)

- More effective in removing particles of a given size
- More cost efficient than other technologies to remove small particles
- Nanofiltration can be engineered in many different ways (design flexibility)

Common Incorrect Answer:

- Can remove smaller particles than existing technologies (RO removes smaller particles)

3. Describe three ways in which nanofilters can operate differently than traditional filters to purify water: (2 points each, 6 points total)

- Layering: Nanomembranes can be uniquely designed in layers. This allows different parts of the membrane (the different layers) to be made out of different materials and have different properties to target different contaminants.
- Embedded Agents: Can embed specialized substances that do specific jobs in relation to certain kinds of contaminants – for example a chemical that kills bacteria on contact
- Water Channels: Create hydrophilic tubes in membranes that "pull" water through while keeping everything else out
- Electrostatic Repulsion 1: You can weave into the membrane a type of molecule than can conduct electricity and repel oppositely charged particles, but let water through.
- Electrostatic Repulsion 2: Pores of one to two nanometers in diameter create an electric field over the opening. This electric field is negative and repels negatively charged particles dissolved in water
- Self-Cleaning: Can send signal for them to self-clean (remove fouling residue)
- Less pressure is needed than conventional RO filters