Unit Overview

Teacher Materials

Contents

For Anyone Planning to Teach Nanoscience… Read This First!

Nanoscience Defined

Nanoscience is the name given to the wide range of interdisciplinary science that is exploring the special phenomena that occur when objects are of a size between 1 and 100 nanometers (10^{-9} m) in at least one dimension. This work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge.

Nanoscience is "Science-in-the-Making"

Introducing students to nanoscience is an exciting opportunity to help them experience science in the making and deepen their understanding of the nature of science. Teaching nanoscience provides opportunities for teachers to:

- Model the process scientists use when confronted with new phenomena
- Address the use of models and concepts as scientific tools for describing and predicting chemical behavior
- Involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations
- Engage and value our student knowledge beyond the area of chemistry, creating interdisciplinary connections

One of the keys to helping students experience science in action as an empowering and energizing experience and not an exercise in frustration is to take what may seem like challenges of teaching nanoscience and turn them into constructive opportunities to model the scientific process. We can also create an active student-teacher learning community to model the important process of working collaboratively in an emerging area of science.

This document outlines some of the challenges you may face as a teacher of nanoscience and describes strategies for turning these challenges into opportunities to help students learn about and experience science in action. The final page is a summary chart for quick reference.

Challenges & Opportunities

1. You will not be able to know all the answers to student (and possibly your own) questions ahead of time …

Nanoscience is new to all of us as science teachers. We can (and definitely should) prepare ahead of time using the resources provided in this curriculum as well as any others we can find on our own. However, it would be an impossible task to expect any of us to become experts in a new area in such a short period of time or to anticipate and prepare for all of the questions that students will ask.

… This provides an opportunity to model the process scientists use when confronted with new phenomena.

Since there is no way for us to become all-knowing experts in this new area, our role is analogous to the "lead explorer" in a team working to understand a very new area of science. This means that it is okay (and necessary) to acknowledge that we don't have all the answers. We can then embrace this situation to help all of our students get involved in generating and researching their own questions. This is a very important part of the scientific process that needs to occur before anyone steps foot in a lab. Each time we teach nanoscience, we will know more, feel more comfortable with the process for investigating what we don't know, and find that there is always more to learn.

One strategy that we can use in the classroom is to create a dedicated space for collecting questions. This can be a space on the board, on butcher paper on the wall, a question "box" or even an online space if we are so inclined. When students have questions, or questions arise during class, we can add them to the list. Students can be invited to choose questions to research and share with the group, we can research some questions ourselves, and the class can even try to contact a nanoscientist to help us address some of the questions. This can help students learn that conducting a literature review to find out what is already known is an important part of the scientific process.

2. Traditional chemistry and physics concepts may not be applicable at the nanoscale level …

One way in which both students and teachers try to deal with phenomena we don't understand is to go back to basic principles and use them to try to figure out what is going on. This is a great strategy as long as we are using principles and concepts that are appropriate for the given situation.

However, an exciting but challenging aspect of nanoscience is that matter acts differently when the particles are nanosized. This means that many of the macro-level chemistry and physics concepts that we are used to using (and upon which our instincts are based) may not apply. For example, students often want to apply principles of classical physics to describe the motion of nanosized objects, but at this level, we know that quantum mechanical descriptions are needed. In other situations it may not even be clear if the macroscale-level explanations are or are not applicable. For example, scientists are still exploring whether the models used to describe friction at the macroscale are useful in predicting behavior at the nanoscale (Luan & Robbins, 2005).

Because students don't have an extensive set of conceptual frameworks to draw from to explain nanophenomena, there is a tendency to rely on the set of concepts and models that they do have. Therefore, there is a potential for students to incorrectly apply macroscale-level understandings at the nanoscale level and thus inadvertently develop misconceptions.

… This provides an opportunity to explicitly address the use of models and concepts as scientific tools for describing and predicting chemical behavior.

Very often, concepts and models use a set of assumptions to simplify their descriptions. Before applying any macroscale-level concept at the nanoscale level, we should have the students identify the assumptions it is based on and the situations that it aims to describe. For example, when students learn that quantum dots fluoresce different colors based on their size, they often want to explain this using their knowledge of atomic emission. However, the standard model of atomic emission is based on the assumption that the atoms are in a gaseous form and thus so far apart that we can think about their energy levels independently. Since quantum dots are very small crystalline solids, we have to use different models that think about the energy levels of the atoms together as a group.

By helping students to examine the assumptions a model makes and the conditions under which it can be applied, we not only help students avoid incorrect application of concepts, but also guide them to become aware of the advantages and limitations of conceptual models in science. In addition, as we encounter new concepts at the nanoscale level, we can model the way in which scientists are constantly confronted with new data and need to adjust (or discard) their previous understanding to accommodate the new information. Scientists are lifelong learners and guiding students as they experience this process can help them see that it is an integral and necessary part of doing science.

3. Some questions may go beyond the boundary of our current understanding as a scientific community…

Traditional chemistry curricula primarily deal with phenomena that we have studied for many years and are relatively well understood by the scientific community. Even when a student has a particularly deep or difficult question, if we dig enough we can usually find ways to explain an answer using existing concepts. This is not so with nanoscience! Many questions involving nanoscience do not yet have commonly agreed upon answers because scientists are still in the process of developing conceptual systems and theories to explain these phenomena. For example, we have not yet reached a consensus on the level of health risk associated with applying powders of nanoparticles to human skin or using nanotubes as carriers to deliver drugs to different parts of the human body.

… This provides an opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

While this may make students uncomfortable, not knowing a scientific answer to why something happens or how something works is a great opportunity to help them see science as a living and evolving field. Highlighting the uncertainties of scientific information can also be a great opportunity to engage students in a discussion of how scientific knowledge is generated. The ensuing discussion can be a chance to talk about science in action and the limitations on scientific research. Some examples that we can use to begin this discussion are: Why do we not fully understand this phenomenon? What (if any) tools limit our ability to investigate it? Is the phenomenon currently under study? Why or why not? Do different scientists have different explanations for the same phenomena? If so, how do they compare?

4. Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology, physics, and computer science…

Because of its multidisciplinary nature, nanoscience can require us to draw on knowledge in potentially unfamiliar academic fields. One day we may be dealing with nanomembranes and drug delivery systems, and the next day we may be talking about nanocomputing and semiconductors. At least some of the many areas that intersect with nanoscience are bound to be outside our areas of training and expertise.

… This provides an opportunity to engage and value our student knowledge beyond the traditional areas of chemistry.

While we may not have taken a biology or physics class in many years, chances are that at least some of our students have. We can acknowledge students' interest and expertise in these areas and take advantage of their knowledge. For example, ask a student with a strong interest in biology to connect drug delivery mechanisms to their knowledge about cell regulatory processes. In this way, we share the responsibility for learning and emphasize the value of collaborative investigation. Furthermore, this helps engage students whose primary area of interest isn't chemistry and gives them a chance to contribute to the class discussion. It also helps all students begin to integrate their knowledge from the different scientific disciplines and presents wonderful opportunities for them to see the how the different disciplines interact to explain real world phenomena.

Final Words

Nanoscience provides an exciting and challenging opportunity to engage our students in cutting edge science and help them see the dynamic and evolving nature of scientific knowledge. By embracing these challenges and using them to engage students in meaningful discussions about science in the making and how we know what we know, we are helping our students not only in their study of nanoscience, but in developing a more sophisticated understanding of the scientific process.

References

Luan, B., & Robbins, M. (2005, June). The breakdown of continuum models for mechanical contacts. *Nature 435*, 929-932.

Table 1. Challenges of teaching nanoscience and strategies for turning these challenges into learning opportunities.

	THE CHALLENGE…	PROVIDES THE OPPORTUNITY TO…
1	You will not be able to know all the answers to student (and possibly your own) questions ahead of time	Model the process scientists use when confronted with new phenomena: Identify and isolate questions to answer Work collectively to search for information using available resources (textbooks, scientific journals, online resources, scientist interviews) Incorporate new information and revise previous understanding as necessary Generate further questions for investigation
2	Traditional chemistry and physics concepts may not be applicable at the nanoscale level	Address the use of models and concepts as scientific tools for describing and predicting chemical behavior: Identify simplifying assumptions of the model and situations for intended use Discuss the advantages and limitations of using conceptual models in science Integrate new concepts with previous understandings
3	Some questions may go beyond the boundary of our current understanding as a scientific community	Involve students in exploring the nature of knowing: How we know what we know The limitations and uncertainties of scientific explanation How science generates new information How we use new information to change our understandings
4	Nanoscience is a multidisciplinary field and draws on areas outside of chemistry, such as biology and physics	Engage and value our student knowledge beyond the area of chemistry: Help students create new connections to their existing knowledge from other disciplines Highlight the relationship of different kinds of individual contributions to our collective knowledge about science Explore how different disciplines interact to explain real world phenomena

Fine Filters: Overview, Learning Goals & Standards

Type of Courses:	Chemistry
Grade Levels:	9-12
Topic Area:	Separation of solutions
Key Words:	Nanoscience, nanotechnology, separation of mixtures, filtration, nanofiltration, solutions, water
Time Frame:	4 class periods (assuming 50-minutes classes), with extensions available

Overview

The shortage of clean drinking water is a pressing global issue. In the twentieth century, demand for water increased six fold, more than double the rate of growth of the human population. At the same time, pollution and over-extraction of water in many regions of the world has reduced the ability of supplies to meet the demand. The United Nations estimates that over a billion people lack access to safe drinking water.

Part of the solution to the water crisis comes from filtration technologies that make water clean enough to drink. For water that contains salt, (97% of earth's water), reverse osmosis is now in use for removing sodium ions. Reverse osmosis is an expensive process, because it requires high pressure—and hence more energy in the form of electricity—to force the affluent (impure water) through the filter membrane.

For water that does not contain salt, a new and more cost-effective technology—nanofiltration—is just beginning to be used. Nanofiltration can remove minerals, sugars, and color from water, and costs much less than reverse osmosis because the process requires much less pressure. There are a multitude of research efforts to develop nanomembranes for water filtration. Researchers anticipate that several forms of this new technology will be available in the next few years. This new generation of membranes is designed to be equally effective as currently used purification treatments, but significantly less expensive so that poor communities can afford clean drinking water.

Enduring Understandings (EU)

What enduring understandings are desired? Students will understand:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.
3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.
4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

Essential Questions (EQ)

What essential questions will guide this unit and focus teaching and learning?

1. Why are water's unique properties so important for life as we know it?
2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not?

Key Knowledge and Skills (KKS)

What key knowledge and skills will students acquire as a result of this unit? Students will be able to:

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.
2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.
3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.
4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

Prerequisite Knowledge

This unit assumes that students are familiar with the following concepts or topics:

1. Atoms, molecules, ions.
2. Homogeneous and heterogeneous solutions.
3. Solute-solvent interaction between ionic and molecular solutes and water.

NSES Content Standards Addressed

K-12 Unifying Concepts and Process Standard

As a result of activities in grades, K-12, all students should develop understanding and abilities aligned with the following concepts and processes: (1 of the 5 categories apply)

- Form and function

Grades 9-12 Content Standard A: Scientific Inquiry

Abilities Necessary to Do Scientific Inquiry

- **Design and conduct scientific investigations.** Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. (12ASI1.2)

- **Formulate scientific explanations and models.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation. (12ASI1.4)
- **Communicate and defend a scientific argument.** Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments. (12ASI1.6)

Grades 9-12 Content Standard B: Physical Science

Structure and Properties of Matter

Compounds. The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them. (12BPS2.4)

Grades 9-12 Content Standard E: Science and Technology

Abilities of Technological Design

- **Propose designs and choose between alternative solutions.** Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes. (12EST1.2)
- **Communicate the problem, process, and solution.** Students should present their results to students, teachers, and other in a variety of ways, such as orally, in writing, and in other forms—including models, diagrams, and demonstrations. (12EST1.5)

Grades 9-12 Content Standard F: Science in Personal and Social Perspectives

Personal and Community Health

- **Selection of foods and eating patterns determine nutritional balance.** Nutritional balance has a direct effect on growth and development and personal well-being. Personal and social factors—such as habits, family income, ethnicheritage, body-size, advertising, and peer pressure—influence nutritional choices. (12FSPSP1.5)

Population Growth

- **Populations can reach limits to growth**. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of earth systems to support human beings. Changes in technology can cause significant changes, either positive or negative, in carrying capacity. (12FSPSP2.1)

Natural Resources

- **Human populations use resources in the environment in order to maintain and improve their existence**. Natural resources have been and will continue to be used to maintain human populations. (12FSPSP3.1)
- **The earth does not have infinite resources**; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed. (12FSPSP3.2)

Environmental Quality

- **Many factors influence environmental quality.** Factors that students might investigate include population growth, resource use, population distribution, over-consumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth. (12FSPSP4.3)

Science and Technology in Local, National, and Global Challenges

- **Science and technology are essential social enterprises**, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge. (12FSPSP6.1)
- **Understanding basic concepts and principles of science and technology should precede active debate** about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges. (12FSPSP6.2)

Unit at a Glance

Overview

The Fine Filters Unit has been designed in a modular fashion to allow you maximum flexibility in adapting it to your student's needs. Lesson 1 provides an introduction to the context and human need for clean drinking water. Combined with Lesson 3 (Nanofiltration), they make up the basic sequence for the unit. Lesson 2 is an extension that reviews some of the science basics of water. In particular, it reviews the structure of water and its unique properties based on the quantum mechanical model of the atom, the shape of the water molecule and the distribution of charge.

Lesson	Basic Sequence	Optional Extensions
Lesson 1: The Water Crisis	√	
Lesson 2: The Science of Water		√
Lesson 3: Nanofiltration	√	

Most lessons contain an interactive presentation and one or more options for activities so you can tailor the depth and duration of the lesson to meet your needs. The following pages contain a suggested sequencing of activities for the unit, but of course there are other combinations possible.

Suggested Sequencing of Activities for Unit

Lesson	Teaching Days	Main Activities and Materials	Learning Goals	Assessment	Homework
Lesson 1: The Water Crisis	2 days: *Day 1*	The Water Crisis: PowerPoint and Discussion Initial Ideas: Student Worksheet	EU: 1 KKS: 1	Initial Ideas Worksheet	Student Data Worksheet
	Day 2 (10 min only for quiz)	Take and review quiz		Water Crisis Quiz	
Lesson 2: The Science of Water (Optional)	3 days: *Day 1*	Science of Water PowerPoint and Discussion	EU: 2 KKS: 3, 4		Read Science of Water Lab Activity and generate hypotheses
	Day 2	Science of Water Lab Activities		Reflection on Guiding Questions	Reflection on Guiding Questions
	Day 3 (35 min)	Reflection on Guiding Questions Take and review quiz		Science of Water Quiz	
Lesson 3: Nanofiltration	3 days: *Day 1*	Nanofiltration: PowerPoint and Discussion Which Method is Best Activity	EU: 3, 4 KKS: 2, 3	Which Method is Best Worksheet	Nanofiltration: Student Reading Read Filtration Lab and generate hypotheses
	Day 2	Comparing Nanofilters to Conventional Filters Lab Activity		Filtration Lab Activity Worksheet	New Nano-Membranes Student Reading
	Day 3	Cleaning Jarny's Water Discuss Nano-Membranes Reading Discussion of Reflection on Guiding Questions		Jarny Student Report Final Reflections Worksheet	

What **enduring understandings (EU)** are desired? Students will understand:

1. A shortage of clean drinking water is one of the most pressing global issues.
2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.
3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process.
4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.

What **essential questions (EQ)** will guide this unit and focus teaching and learning?

1. Why are water's unique properties so important for life as we know it?
2. How do we make water safe to drink?
3. How can nanotechnology help provide unique solutions to the water shortage?
4. Can we solve our global water shortage problems? Why or why not

What **key knowledge and skills (KKS)** will students acquire as a result of this unit? Students will be able to:

1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.
2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.
3. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.
4. Describe the basic structure and charge distribution of water.
5. Explain how hydrogen bonding accounts for many of water's unique properties.

Alignment of Unit Activities with Learning Goals

	Lesson 1	Lesson 2	Lesson 3
Presentation	*Introduction/ Water Crisis*	*Science of Water*	*Nanofiltration*
Activity	*Student Reading, Data Worksheet*	*Water Lab Activity*	*Student Reading/ Jarny/ Filtration Lab*
Assessment	*Quiz/ Initial Ideas Worksheet*	*Label Results/ Quiz/ Reflection Worksheet*	*Lab Results/ Jarny, Reflection Worksheets*
Learning Goals			
Students will understand…			
EU 1. A shortage of clean drinking water is one of the most pressing global issues	•		
EU 2. As a result of water's bent shape and polarity, water has unique properties, such as an ability to dissolve most substances. These properties are responsible for many important characteristics of nature.		•	
EU 3. Pollutants can be separated from water using a variety of filtration methods. The smaller the particle that is to be separated from a solution, the smaller the required pore size of the filter and the higher the cost of the process			•
EU 4. Innovations using nanotechnology to create a new generation of membranes for water filtration are designed to solve some critical problems in a cost-effective way that allows for widespread use.			•
Students will be able to…			
KKS1. Describe the global distribution of clean drinking water and explain some of the causes and consequences of water scarcity.	•		
KKS2. Describe different types of filtration in terms of the pore size of the filter, substances it can separate, and cost of use.			•
KKS4. Use laboratory procedures to compare the relative effectiveness of different filtration methods on particle separation.			•
KKS3. Describe the basic structure and charge distribution of water.		•	
KKS5. Explain how hydrogen bonding accounts for many of water's unique properties.		•	

Alignment of Unit Activities with Curriculum Topics

Chemistry

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Structure of Matter	Electron Configuration	Atomic Structure	• Lesson 2 (L2): Science of Water	**Slides** • L2: 3-10
		Bonding	• Lesson 2 (L2): Science of Water	**Slides** • L2: 11-19
Chemical Equilibrium	Solutions	Nature of solutions Precipitates Common Ion Effect	• Lesson 2 (L2): Science of Water • Lesson 3 (L3): Nanofiltration	**Slides** • L2: (all) • L3: (all) **Activity/Handout** • L2 o Science of Water Labs o Reflecting on Guiding Questions • L3 o The Filtration Spectrum o Which Method is Best? o Cleaning Jarny's Water o Comparing Filtration to Nanofiltration Lab Activities

Biology

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Nature of Life	The Chemistry of Life	The Nature of Matter; Properties of Water; Carbon Compounds	**Fine Filters** • Lesson 2 (L2): Science of Water	**Slides** • L2: 20-32 **Activity/Handout** • L2 o Science of Water Labs o Science of Water Quiz

Physics

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Light and Optics	Light Rays	Electron clouds Orbitals Charges	**Fine Filters** • Lesson 2 (L2): The Science of Water	**Slides** • L2: 5-16

Environmental Science

Unit Topic	Chapter Topic	Subtopic	Fine Filters Lessons	Specific Materials
Water	Our Water Resources	Solutions to Water Shortages	• Lesson 1 (L1): The Water Crisis	**Slides** • L1: 1-27 **Activity/Handout** • The World-Wide Water Shortage: Student Reading • The Water Crisis: Student Data Worksheet • The Water Crisis Initial Ideas • Student Quiz

	Freshwater Pollution	Wastewater Treatment Plants	• Lesson 2 (L2): The Science of Water
			• Lesson 3 (L3): Nanofiltration
				Slides
				• L2: 1-34
				Activity/Handout
				• L2: The Science of Water Quiz
				• L3:
				  ○ Comparing Filtration and Nanofiltration Lab Activities
				  ○ Reflecting on the Guiding Questions

		Pathogens	• Lesson 3 (L3): Nanofiltration	**Slides** • L3: 1-21 **Activity/Handout** • Reading: New Nano- Membranes • Which Method is Best? • Jarny Water Activity • Comparing Filtration and Nanofiltration Lab Activities • Reading: New Nano-Membranes

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