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EDVOTEK® LESSON PLAN:

Tiny Channels, Big Science: Engineering Design with Paper Microfluidics

Grade level: 9-12, College
Subject area: Biotechnology

Version 260701

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Think for one second:

- ***Have you ever used a microfluidics device?***
- ***Are you wondering what microfluidics is?***
- ***Do you think it must be too complicated for you?***

Well, chances are that you are wrong! If you have ever taken a COVID test, used a blood glucose test strip, or changed an inkjet printer ink cartridge, you've used a microfluidics device.

Microfluidics is the science and technology of manipulating extremely small volumes of liquid through tiny channels, often on devices no larger than a credit card or even a fingertip.

These devices have tiny pumps, channels, and chambers that are designed to precisely control how fluids move and interact. This allows us to perform complex experiments using only microliters of sample and reagent.

Want to try making your own microfluidics device? You are in luck! In this activity, you will explore the basic principles of microfluidics and discover how tiny droplets can solve big scientific challenges.

Learning Objectives:

Students will:
- Explain how capillary action drives fluid flow without pumps.
- Investigate how different wick sizes and materials affect flow rate.
- Relate paper microfluidics to point-of-care medical diagnostics and environmental testing.

Educator overview:

Our materials are designed to support the concepts and content of the Next Generation Science Standards, through its connections to specific performance expectations and scientific practices. This experiment covers multiple NGSS disciplinary core ideas and topics as described by the Middle and/or High School Science Standards. These materials have not been endorsed or reviewed by NextGenScience or WestEd.

Performance Expectations:

- **Middle School**
  ETS1-3: Students analyze data from multiple tests to determine similarities and differences when changing the width, length, substrate, or flow paths of paper microchannel chips.
  ETS1-4: Students will use an iterative testing process to design and optimize paper microfluidics devices

- **High School**
  ETS1-2: Students select a real-world problem and design a lab-on-a-chip system to address it.
  ETS1-3: Students will use an iterative testing process to optimize flow rate, mixing, sample volume, and device design. Solutions will focus on meeting specifications and trade offs to performance.

- **Science & Engineering Practices**
  Planning and Carrying Out Investigations; Analyzing and Interpreting Data; Developing and Using Models.

- **Crosscutting Concepts:**
  Cause and Effect; Systems and System Models; Scale, Proportion, and Quantity.

  Through student research and written answers to the discussion questions, this experiment can be used in the classroom laboratory as an exercise to develop important critical thinking and literacy skills (specifically CCSA.ELA-LITERACY.RST.9-10.1 through RST.9-10.10).

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Background

You don't need complicated pumps or microchannels to play with microfluidics at home. Many laboratory tests are microfluidics devices that use paper to wick liquid samples through the test chamber. At the microscopic level, paper is a network of cellulose fibers with pockets of air trapped within, creating pores. When the liquid sample is spotted on the test strip, capillary action pulls the liquid through the pores without an external pump. Modern paper microfluidic devices use these principles to perform diagnostic tests for diseases, detect contaminants in drinking water, and analyze food samples.

The rate of fluid movement through the paper depends on the physical properties of the wick.

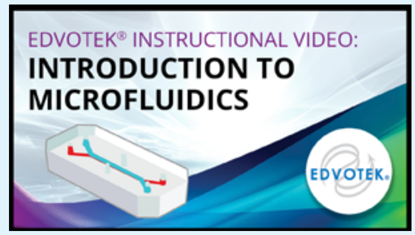
This includes:

- Strip width
- Strip length
- Paper porosity
- Fluid viscosity
- Surface tension

Intro Video:

Scan to Watch ⬇

See microfluidics in action in this short introductory video.



Five Facts You Should Know About Microfluidics:

1. Many microfluidic channels are thinner than a human hair.
2. At the microscale, liquids usually flow in smooth, parallel layers called laminar flow rather than turbulent flow.
3. Because there is little or no turbulence, fluids in microfluidic devices mix through diffusion.
4. Some microfluidic devices integrate multiple laboratory functions onto a single chip, earning them the name "lab-on-a-chip".
5. Scientists are using microfluidic "organ-on-a-chip" devices to mimic the function of human tissues, helping researchers study diseases and test new medicines without relying solely on animal models.

Capillary Flow

In this module, students investigate which paper substrate performs best.

What You Need:

- ❑ Different types of paper, including filter paper, coffee filters, paper towels, and watercolor paper.
- ❑ Pencil
- ❑ Scissors
- ❑ Ruler
- ❑ Water and food coloring
- ❑ Transfer pipettes or adjustable volume micropipettes and tips
- ❑ Stopwatch
- ❑ Data table

Video Tutorial:

Scan to Watch ⬇

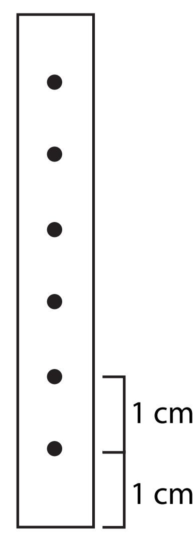
For a quick video example, check this out!

Protocol:

1. **ADD** one drop of food coloring to 5 mL of water. This is your **sample solution**.

2. **CUT** papers into 1cm wide strips. **These are you sample strips.**

3. Using a pencil, **DRAW** a dot 1 cm from the end of the paper. Using that dot as a starting point, draw additional dots every 1 cm. These will be your **measurement points.** ***NOTE: be sure to use PENCIL, not PEN! Some inks are water soluble and will spread during the experiment.***



4. Using a transfer pipette, **APPLY** one large drop of your sample solution to each of the sample strips. **START** your timer immediately.

5. **INCUBATE** the test strips for three minutes, checking the progress of the samples every 15 seconds and make notes about what you see. Data can include:
   a. Time to travel to each cm marking
   b. Total distance travelled each 10 seconds
   c. Final distance travelled

6. **ANALYZE** your data. You can use the numbers to calculate flow rate (distance travelled over time)

7. **CHANGE** a variable and repeat the experiment again. Below are some ideas for exploration:
   a. Do specific papers wick the sample more quickly than others?
   b. Do the dimensions of the wick change the way the fluid flows?
   c. Does the flow rate change over time?
   d. What happens if you use oil instead of water?
   e. What happens if you apply a different color to each end of the wick?

Engineering Challenges:

Can you redesign your microfluidics system to meet these goals?

- Fastest delivery
- Complete color mixing
- Sequential delivery to reaction zones

Extension: Create a Colorimetric Biosensor that detects differences in pH

Create "reaction zones" by spotting small drops of Universal pH indicator (or another safe indicator dye) onto the paper before running the experiment. Allow it to dry thoroughly before use. Test different solutions (e.g., vinegar, baking soda solution, water, lemonade) and observe color changes only in designated detection zones. This models the way paper microfluidic diagnostic devices like COVID tests localize chemical reactions.

Sketch Your Solution Here:

Discussion Questions:

1. Why don't paper microfluidic devices require pumps?
2. How did channel width or length affect the flow rate?
3. How did the different papers affect the flow rate?
4. How could your design be modified to perform multiple diagnostic tests from a single sample?

Research Question:

What advantages do paper microfluidic devices offer over traditional laboratory instruments?

Careers that use Microfluidics

The broad utility of microfluidics in biotechnology, engineering, anatomy, medicine, and environmental science has made it an important part of our everyday life. Below are a few jobs where microfluidics is used. What other careers would microfluidics be important for?

- **Biomedical Engineer**
  Designs microfluidic devices for medical diagnostics, drug delivery, and lab-on-a-chip technologies.

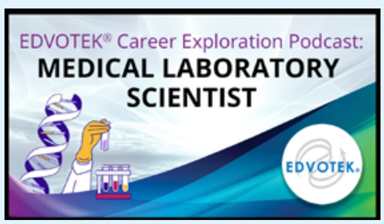
- **Medical Laboratory Scientist**
  Uses microfluidic instruments to analyze blood, tissue, DNA, and other patient samples for disease diagnosis.

- **Chemical Engineer**
  Develops microfluidic systems for chemical processing, reaction optimization, and manufacturing of pharmaceuticals and specialty chemicals.

- **Biotechnology Research Scientist**
  Uses microfluidics for DNA sequencing, cell analysis, protein studies, and drug discovery.

- **Environmental Scientist**
  Applies portable microfluidic devices to detect pollutants, pathogens, and contaminants in water, soil, and food samples.

Edvotek Career Exploration Podcast:
Medical Laboratory Scientist



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Microfluids Vocabulary

1. **Microfluidics**
   The science and technology of manipulating and controlling very small amounts of liquid in microscopic channels.

2. **Microliter**
   A unit of volume equal to one-millionth of a liter. Microfluidic devices often use only a few microliters of liquid. Often written as μL.

3. **Microchannel**
   A tiny pathway, often narrower than a human hair, through which fluids travel in a microfluidic device.

4. **Laminar Flow**
   A type of fluid flow in which liquids flow next to one another in smooth parallel layers without mixing.

5. **Turbulent Flow**
   A chaotic type of fluid flow where liquids mix and swirl as it travels. Turbulent flow is common in rivers and large pipes.

6. **Diffusion**
   Passive movement of molecules from an area of high concentration to an area of low concentration.

7. **Capillary Action**
   The movement of a liquid through tiny channels or pores without the use of a pump.

8. **Surface Tension**
   The force created by the attraction between liquid molecules at the surface of a liquid, allowing droplets to form and helping drive capillary flow.

9. **Viscosity**
   A measure of a liquid's resistance to flowing. Oil has a higher viscosity than water.

10. **Reagent**
    A chemical or biological substance used to produce a reaction or detect the presence of another substance.

11. **Sample**
    The small amount of material, such as blood, saliva, or water, that is tested in a microfluidic device.

12. **Lab-on-a-Chip**
    A miniature device that combines one or more laboratory functions onto a single chip, allowing rapid analysis using tiny amounts of liquid.

13. **Paper Microfluidics**
    A type of microfluidic device that uses paper and capillary action to move fluids without pumps, commonly used in rapid diagnostic tests.

14. **Point-of-Care Testing**
    Medical testing performed at or near the patient, providing rapid results without sending samples to a laboratory. Often abbreviated to POCT.

15. **Biomarker**
    A measurable biological molecule, such as a protein or DNA sequence, that can indicate health, disease, or the effectiveness of a treatment.

Microfluidics Word Search

A	L	P	P	M	A	Q	C	V	C	V	X	V	M	A	L	B	S	D	T
A	I	U	O	W	J	S	X	H	E	Y	S	J	G	D	N	O	C	W	K
M	F	K	I	N	U	C	V	R	E	A	G	E	N	T	N	E	I	O	W
E	Q	K	N	E	G	I	F	O	L	Z	M	N	Z	P	M	X	D	H	Z
C	G	O	T	G	S	D	W	B	M	B	M	H	D	U	C	F	I	L	B
A	X	U	O	Y	T	I	S	O	C	S	I	V	I	V	F	H	U	T	J
P	N	R	F	T	C	U	T	W	Q	Y	C	J	F	Y	L	N	L	O	B
I	O	E	C	M	U	L	U	W	Q	V	R	U	F	R	X	N	F	S	O
L	I	K	A	I	P	F	R	I	W	P	O	G	U	K	I	B	O	B	B
L	S	R	R	C	F	O	B	L	A	J	L	U	S	A	E	C	R	Z	N
A	N	A	E	R	V	R	U	H	T	M	I	R	I	H	O	G	C	K	T
R	E	M	T	O	D	C	L	T	C	Z	T	K	O	K	R	O	I	K	I
Y	T	O	E	C	A	I	E	Q	B	G	E	L	N	C	G	Q	M	L	G
A	E	I	S	H	G	M	N	I	V	X	R	X	J	J	Q	M	I	P	L
C	C	B	T	A	W	R	T	H	B	J	R	C	A	O	P	X	O	B	Z
T	A	N	I	N	P	E	F	L	A	B	O	N	A	C	H	I	P	O	O
I	F	D	N	N	C	P	L	C	H	D	Y	E	N	G	O	T	C	N	R
O	R	Y	G	E	M	A	O	B	W	O	L	F	R	A	N	I	M	A	L
N	U	F	H	L	P	P	W	H	E	I	L	K	N	D	R	J	T	R	Z
G	S	W	J	Y	O	S	A	M	P	L	E	Q	T	O	R	U	I	I	H

Word Bank:

Microfluidics
Microliter
Microchannel
Laminar Flow
Turbulent Flow
Diffusion
Capillary Action
Surface Tension
Viscosity
Reagent
Sample
Lab-on-a-Chip
Paper Microfluidics
Point-of-Care Testing
Biomarker

The instructor answer key for this activity is available upon request from EDVOTEK®.