Teacher's Guide

Multifaceted Microfluidics: Three simple methods to create a microfluidic device

Purpose: The purpose of this teaching module is to help students grasp the relevance of miniaturizing liquid flow-through systems. By design, this module may be utilized in one of two ways. It may be used to teach microfluidics or it may use microfluidics to teach basic scientific principles. The lesson is open ended so that the teacher can choose the "fabrication" method and the experimental topic to be examined.

Grade Level: High school

Subject area: Chemistry

Time required: a minimum of in class time: (2) 55 minutes

Learning Objectives: 1. Design & build a microfluidic device; 2. Understand concepts of fluidic flow; 3. Design and test an experiment using fluids.

Summary: This module is open-ended to allow for use in a number of classroom settings. The importance here is to permit the teacher to choose the technique provided and tailor the technique to the scientific principle. The students will create their own microfluidic devices and utilize their devices in a manner similar to those used in a laboratory setting. This brings to the chemistry classroom real world applications of current technology.

The lesson provides three different techniques to create microfluidic devices. The methods use safe and simple materials including Jell-O®, Wikki Stix®, Shrinky Dinks®, and a polymer, polydimethylsiloxane (PDMS). These designs are an example of soft lithography in a less rigorous setting - no cleanroom required. The teacher may choose which "fabrication" method will be used and what concept will be explored with the device. Students may examine laminar flow, diffusion, mixing, sedimentation etc. The lesson is flexible enough to present a problem to the students and have them design their own device to test the problem.

Lesson Background: Microfluidic devices have enhanced basic research and are currently demonstrating potential for use in diagnostic medicine. Miniaturized devices allow for faster response times, smaller sample size and low cost sample/specimen analysis. Applications for microfluidic devices are almost limitless in the areas of biology, chemistry, physics and engineering.

Microfluidics is a technique for manipulating liquid samples at very small scales. These micro and nano-sized devices that are sometimes called lab-on-a-chip because of their applications in biochemical testing and analysis. They typically have sets of channels, sensors, and mixing chambers that can run several tests at one time. Sample size may be as small as a drop of blood or urine. Common examples from everyday life include: home pregnancy tests, strept tests, drug tests, yeast infection tests, and glucose monitoring.

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The history of the development of microfluidic devices is connected to early semiconductor advances and demonstrates the interconnection of several fields. An excellent overview of its history can be found at the Elveflow (see resources). Fabrication of these devices uses a method called soft lithography, developed in the late 1990's by Harvard Professor George Whitesides. This method requires use of a cleanroom to fabricate the master mold using photolithography. Current research is developing non-cleanroom methods including injection molding ad 3-D printing.

An excellent overview of microfluidics can be found at Lutetium Project's YouTube series *Adventures in Microfluidics #1-3*. These short (less than 7 minutes each) provide good information and are suggested for use with your students as an introduction to the lesson. Other useful resources on microfluidics, including educational lessons are listed in the resource section.

Resources:

Below are published lessons using Shrinky Dinks for microfluidic devices:

- Chen, C-S, D.N. Breslauer, J.I. Luna, A. Grimes, W-C. Chin, L.P. Lee and M. Khine (2008) Shrinky-Dink microfluidics: 3D polystyrene chips. Lab on a Chip 8:622-624.
- Grimes, A. D.N. Breslauer, M. Long, J. Pegan, L.P. Lee and M. Khine (2008) Shrinky-Dink microfluidics: rapid generation of deep and rounded patterns. Lab on a Chip, 8: 170-172.
- Hair, G. Make a Microfluidic Device to Investigate Properties of Solutions. Access at:
- Hemling, M. J. A. Crooks, P.M. Oliver, K. Benner, J. Gilberston, G.C. Lisensky, and D.B. Weibel (2013) Microfluidics for High School Chemistry Students. J. of Chemical Ed. 91:112-118.
- Microfluidic Devices. Accessed at: https://chem.beloit.edu/edetc/nanolab/shrink/index.html
- Ngyuen, D., J. McLane, V. Lew, J. Pegan and M. Khine (2011) Shrink-film microfluidic education modules: Complete devices within minutes. Biomicrofluidics 5: 022209.
- Yang, Cheng Wei T., Ouellet, Eric, and Lagally, Eric T. Using Inexpensive Jell-O Chips for Hands-On Microfluidics Education. Anal.Chem. 2010, **82**, 5408-5414.
- Fintschenko, Yolanda. Education: A modular approach to microfluidics in the teaching laboratory. Lab Chip, 2011, **11**, 3394-3340.
- Making Microfluidic Devices Using Jell-O: www.teachengineering.org/view_activity.php?url=collection/van_/activities/van_feelbetter_lesson02_activity02/van_feelbetter_lesson02_activity_02.xml
- Gelatin Microfluidics: https://www.nnci.net/node/5371
- Lab on a Slab: https://www.nnci.net/node/5345

Other useful resources:

- History of Microfluidics: https://www.elveflow.com/microfluidic-reviews/general-microfluidics/history-of-microfluidics/
- Overview: What is microfluidics? https://ufluidix.com/resources/definitions/
- Wikipedia: Lab on a chip. https://en.wikipedia.org/wiki/Lab-on-a-chip
- Wikipedia: Microfluidics. https://en.wikipedia.org/wiki/Microfluidics
- What is Microfluidics? https://www.news-medical.net/life-sciences/What-is-Microfluidics.aspx

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- Microfluidics Adventures #1 – 3 from The Lutetium Project on YouTube. https://www.youtube.com/watch?v=b8zE2i755-k; https://www.youtube.com/watch?v=68p3qAm4i7U; https://www.youtube.com/watch?v=EYuyRUjnTgc
- Microfluidics: A general overview of microfluidics. https://www.elveflow.com/microfluidic-reviews/general-microfluidics/a-general-overview-of-microfluidics/
- Nanotechnology 101 from the National Nanotechnology Initiative https://www.nano.gov/nanotech-101
- Introduction to Nanotechnology https://www.understandingnano.com/introduction.html

Pre-requisite Knowledge: Students should understand mixtures and solutions; molecular bonding, laminar flow, viscosity.

Safety Information: Caution should be observed when using a hot oven or heated oil. Polydimethylsiloxane (PDMS) is a silicon based elastomeric polymer that is inert, non toxic and safe to handle. If probes or biopsy punches are used to make holes, stress proper sharps behavior. Gloves and safety eyewear should be worn when handling chemicals.

Teaching Strategy:

- Have the students view the *Microfluidics Adventure*s videos before beginning the activity
- Students (in groups) can define the vocabulary. As a class, discuss which definitions proved difficult and if there are additional terms they would like to define after viewing the three videos.
- Determine which fabrication method will be used and what variables will be tested. Assign variables to groups of students for testing.

Materials: *(will depend on method used)*

- Styrofoam plates (full size)
- Jell-O® gelatin (use lemon or peach for better visualization)
- Boiling H_2O
- Measuring cup
- Bowl to mix Jell-O®
- Refrigerator
- Wikki-Stix® (available online)
- Scotch tape
- Double sided scotch tape
- Aluminum pie pans
- Plastic petri dishes (150mm)
- Food coloring
- Shrinky-Dinks® (available online)
- Laser-Jet printer or marking pens

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- Scissors, scalpel, razor blades
- Toaster oven
- Vegetable oil
- Hot plate
- 400 or 500 mL beaker
- Thermometer
- PDMS (polydimethylsiloxane). (sources below)
- Mixing cup
- Plastic spoon or spatula
- Vacuum chamber/desiccator
- Glass slides (50mm x 75mm)
- Blunt needles, probes, or biopsy punch
- Syringes for injection of fluids (1 ml or 5 ml)
- Pipets
- Oven capable to heating to 60°C
- Materials for testing – will vary based on experiments
- Safety gloves and goggles

Vocabulary: (definitions from open source materials such as Wikipedia; provided in Student Guide). Add additional terms depending on your experimental variables.

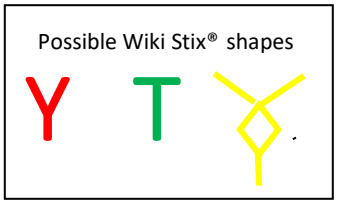
Solution	Laminar flow
Mixture	Viscosity
Diffusion	Nanoscale
Soluble	Nanometer
Insoluble	Nanotechnology

Advance Preparation:
PDMS can be purchased online at various suppliers with some listed here:

- DigiKey electronics: https://www.digikey.com/en/resources/about-digikey
- Slygard 184 Elastomer Kit at Dow https://www.dow.com/en-us/pdp.sylgard-184-silicone-elastomer-kit.01064291z.html

Amazon: https://www.amazon.com/Electron-Microscopy-Sciences-Sylgard-184/dp/B00K335I0G

Directions for the Activity: Three methods to make device



1. JELL-O® activity:
This is a macro model of a microfluidic device. Each student will need a Styrofoam plate and 6-8 Wikki-Stix®. Wikki-Stix® can easily be bent into a multitude of forms (T-shaped, Y-shaped or multi- patterns). Have students create their own microfluidic pattern with the Stix. They will place the design on the plate. Use double stick scotch tape to anchor the design to the plate. Anchoring the final design with tape will prevent the JELL-O® sticking to the form. Cool the JELL-O® mixture to room temp before pouring onto the form.

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Directions:
Follow the instructions on the JELL-O® box to make the Jigglers mix.

- Stir 2.5 cups boiling H_2O into a bowl containing the contents of one JELL-O package.
- Mix until completely dissolved.
- Pour the cooled liquid onto a Styrofoam plate completely covering the design.
- Refrigerate overnight.
- Students will carefully peel the Styrofoam plates from the JELL-O® mold and Wikki-Stix® and invert the mold onto an aluminum pie pan. The channels created by the Wikki-Stix® should be face down on the aluminum pan.
- Using a blunt needle/probe or stirring straw, have students punch two holes (number of holes will depend on the design) in the JELL-O® mold. The Stix may provide the holes. One hole will be an inlet hole into which the students will inject fluid; ideally, on opposite ends of the horizontal cross of the T or the upper ends of the Y. The second hole is an outlet hole for the fluid and will be at the base of the stem of the T or Y. Students may also wish to create a device with dual inlets or duel outlets. (Dual inlets should create laminar flow while dual outlets should create less resistance to flow). When using dual inlets use different colors of food dye. The device is now ready for testing.

2. Shrinky-Dinks activity:

This is a micro model of a microfluidic device. Shrinky-Dinks® are heat sensitive plastic sheets (polystyrene) that when heated crosslink or hybridize resulting in the "shrinkage" of the film. The inked area will rise up when heated. In this activity, a design can be drawn or printed from a Laser-Jet printer representing the microfluidic device. The finished product is approximately two-thirds its original size. This technique demonstrates the micro dimensions of a microfluidic device. The template mold can be produced in a matter of minutes.

Directions:

- Students will design their flow-through apparatus and then using a permanent marker they will draw it on the Shrinky-Dink® sheet. *An alternate method* is for the students to design the device using PowerPoint and then print it with a laser printer on the film. Designs should be around 10 - 15 cm^2. Cut out the device leaving about 1 cm around it.
- Follow the instructions for heating the Shrinky-Dinks®. Place the design on a flat surface in a standard toaster oven for 3-5 minutes at 350^{O}F. The plastic will curl while shrinking. They will uncurl after complete shrinking. Continue to bake the Shrinky-Dink® for about 7 minutes after shrinking. The extra time helps the ink stick to the plastic. *An alternate* method proposed by Hemling et al (see resources) is to fill a 500mL beaker 1/3rd full of vegetable oil and heat on a hotplate to 150^{o}C. Using tweezers, place film into the oil and leave until it curls and uncurls (~1 minute). Once completed, place between two glass plates and allow to cool.
- Students will be creating their devices using polydimethylsiloxane or PDMS. Mix according to instructions, typically the mix ratio is 10:1 - base to catalyst. Mix in cups using either a plastic spoon or a stirring stick. It will become white and cloudy with

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bubbles. Degas the mixture using a desiccator/vacuum system. It is recommended to degas the mixing cup for 10-15 minutes before pouring it into petri dish. Place the cut Shrinky-Dink® design (ink side up) in a plastic petri dish. Use double sided tape to hold it in place. Pour the PDMS mixture over the Shrinky-Dink® completely covering the design. Repeat the degassing procedure until all bubbles are eliminated (15-30 minutes). Allow the PDMS to cure at room temperature for 48 hours. *Alternative method* is to bake at 60°C for 2-3 hours or overnight.

- Have students wear gloves to remove the mold. They should GENTLY cut it away with a scalpel/razor blade and remove the mold from the petri dish. The PDMS should show a negative imprint of the pattern.
- Adhere the mold to a glass plate. For student purposes, double-stick tape should suffice. Make sure they gently press to ensure it is completely adhering.
- Using a blunt needle, probe, or biopsy punch, punch holes into the PDMS for inlets and outlets. The device is now ready for testing.

3. Wikki-Stix® with PDMS activity:

This activity falls between the JELL-O® macro scale and the Shrinky-Dink® micro scale.

- Students will design their pattern using the Wikki-Stix®. It must be small enough to fit into the petri dish.
- Press the design onto a plastic petri dish and anchor with double stick tape. Press gently to make sure there are no bubbles between the tape and the device.
- Mix PDMS (polydimethylsiloxane) according to instructions noted above in method 2. Degas as noted above.
- Pour the mixture over the Wikki-Stix® design. Degas again as noted in method 2 above. Allow the PDMS to cure at room temperature for 48 hours or bake at 60°C for 2-3 hours or overnight.
- Have students wear gloves. Using scalpel or razor blade cut the mold and gently remove it from the petri dish. The PDMS should show a negative imprint of the pattern after removing Wikki-Stix®.
- Using double sided tape, adhere the mold to a glass plate. Gently press to adhere.
- Students may leave ends of the Wikki-Stix® exposed for holes and pull the Wikki-Stix carefully through the imprint in a snake-like fashion. If needed, holes can be punched into the PDMS for inlets and outlets. A blunt needle, probe, or biopsy punch will work.

Experimental variables:

As noted in the introduction, the teacher has the option of what fabrication method to use and what experimental variables are to be tested. This would be a great opportunity to have students determine what chemical concept they would like to test and then design a device. Or, the teacher can decide what is to be tested (suggestions below) and have students design their device.

- Test the viscosity of the devices using baby oil for a thick fluid compared to fruit juice.
- Use food coloring to demonstrate laminar flow. Requires two inlets. Use two syringes each containing a different color dye.

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- Use glitter of various sizes to demonstrate particle size versus speed of flow. Put glitter into water and inject the fluid into an inlet.
- Mix two of more solutions to neutralize an acid or a base.

Assessment:

- Students should correctly answer the vocabulary in full and complete sentences. Extra points should be awarded if they provide examples to illustrate the concept.
- Students should correctly and completely answer the questions in the Student Guide. The answers should be thoughtful and demonstrate understanding of the concept.
- If you are having the students design their own device to test a variable(s), it is suggested to create a rubric to assess the work. The rubric could be a 4-point scale ranging from little knowledge of design needed to meet testing variable to excellent design to meet testing variable. While many of the devices may not work properly, credit should be given to creativity and thoughtful design. Execution of the design may not lead to positive results.

Next Generation Science Standards:

- PS1.A Structure and properties of matter
- PS1.B Chemical reactions
- PS2.B Types of interactions
- ETS1.A Defining and delimiting engineering problems
- ETS1.C Optimizing the design solution

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Supporting Programs: NNIN RET Program at Arizona State University NSF - EEC 1200925; National Nanotechnology Coordinated Infrastructure NSF – ECCS 1626183;

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Student Worksheet
(answers in red)

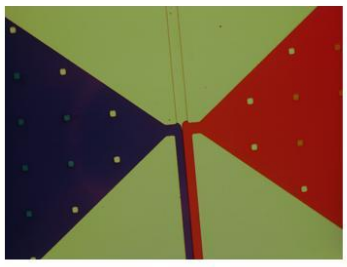
Multifacted Microfluidics

Introduction:

Microfluidics is a technique for manipulating liquid samples at very small scales. These micro and nano-sized devices that are also called lab-on-a-chip because of their applications in biochemical testing and analysis. They typically have sets of channels, sensors, and mixing chambers that can run several tests at one time. Sample size may be as small as a drop of blood or urine. Common examples from everyday life include: home pregnancy tests, strept tests, drug tests, yeast infection tests, and glucose monitoring.

Microfluidic devices have enhanced basic research and are currently demonstrating potential for use in diagnostic medicine. Miniaturized devices allow for faster response times, smaller sample size and low cost sample/specimen analysis. Applications for microfluidic devices are almost limitless in the areas of biology, chemistry, physics and engineering.

The lesson provides three different techhniques to create microfluidic devices. The methods use safe and simple materials including Jell-O®, Wikki Stix, Shrinky Dinks®, and a polymer called PDMS. These designs are an example of soft lithography in a less rigorous setting - no cleanroom required. Typically, to make a microfluidic device one begins by making a mask using photolithography in a cleanroom. You will be making a mask and microfluidic device in your lab using these common and safe materials. Your teacher will decide which method you will use for your fabrication and what experimental variables you will test. Below is an image or a device which demonstrates laminar flow as shown by red dyed and blue dyed fluids entering the same channel.



Photograph of laminar flow in a PDMS device. Courtesy Arizona State University.

Pre lab: Watch the videos from The Lutetium Project – *Microfluidics Adventures #1-3.*
https://www.youtube.com/watch?v=b8zE2i755-k;
https://www.youtube.com/watch?v=68p3qAm4i7U;
https://www.youtube.com/watch?v=EYuyRUjnTgc

Vocabulary: Your teacher may assign the vocabulary as an in class or homework assignment. As a class, you should a discussion about definitions you found difficult or add to the list after viewing the Microfluidics Adventures videos.

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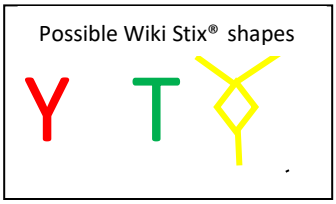
1. *Solution*: a homogeneous mixture composed of two or more substances. In such a mixture, a solute is a substance dissolved in another substance, known as a solvent.
2. *Mixture*: a material made up of two or more different substances which are physically combined. A mixture is the physical combination of two or more substances in which the identities are retained and are mixed in the form of solutions, suspensions, and colloids. Mixing
3. *Diffusion*: Diffusion is the process of a substance spreading out to evenly fill its container or environment. In a solution, a concentrated solute diffuses to spread evenly in its solvent. This is the process where the particles move from high concentration to low concentration.
4. *Soluble*: Solubility is a chemical property referring to the ability for a given substance, the solute, to dissolve in a solvent.
5. *Insoluble*: An insoluble substance is a substance (solid) that will not dissolve in a solvent even after mixing (e.g.; sand and water).
6. *Laminar flow*: a smooth, uniform, non-turbulent flow of a gas or liquid in parallel layers, with little mixing between layers. It is characterized by small values of the Reynolds number.
7. *Viscosity*: the state of being thick, sticky, and semifluid in consistency, due to internal friction.
8. *Nanoscale*: measured in nanometers; typically referring to materials between 1 and 100 nm but others use up to several hundred nanometers.
9. *Nanometer*: $1x10^{-9}$ or one billionth of a meter.
10. *Nanotechnology*: Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. It is the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering.

Materials per group

Directions for the Activity: Three methods to make device



1. JELL-O® activity:

This is a macro model of a microfluidic device. Each student will need a Styrofoam plate and 6-8 Wikki-Stix®. Wikki-Stix® can easily be bent into a multitude of forms (T-shaped, Y-shaped or multi- patterns). Have students create their own microfluidic pattern with the Stix. They will place the design on the plate. Use double stick scotch tape to anchor the design to the plate. Anchoring the final design with tape will prevent the JELL-O® sticking to the form. Cool the JELL-O® mixture to room temp before pouring onto the form.

Directions:
Follow the instructions on the JELL-O® box to make the Jigglers mix.

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- Stir 2.5 cups boiling H_2O into a bowl containing the contents of one JELL-O package.
- Mix until completely dissolved.
- Pour the cooled liquid onto a Styrofoam plate completely covering the design.
- Refrigerate overnight.
- Students will carefully peel the Styrofoam plates from the JELL-O® mold and Wikki-Stix® and invert the mold onto an aluminum pie pan. The channels created by the Wikki-Stix® should be face down on the aluminum pan.
- Using a blunt needle/probe or stirring straw, have students punch two holes (number of holes will depend on the design) in the JELL-O® mold. One hole will be an inlet hole into which the students will inject fluid; ideally, on opposite ends of the horizontal cross of the T or the upper ends of the Y. The second hole is an outlet hole for the fluid and will be at the base of the stem of the T or Y. Students may also wish to create a device with dual inlets or duel outlets. (Dual inlets should create laminar flow while dual outlets should create less resistance to flow). When using dual inlets use different colors of food dye. The device is now ready for testing.

2. Shrinky-Dinks activity:

This is a micro model of a microfluidic device. Shrinky-Dinks® are heat sensitive plastic sheets (polystyrene) plastic film that when heated crosslink or hybridize resulting in the "shrinkage" of the film. In this activity, a design can be drawn or printed from a Laser-Jet printer representing the microfluidic device. The finished product is approximately two-thirds its original size. This technique demonstrates the micro dimensions of a microfluidic device. The template mold can be produced in a matter of minutes.

Directions:

- Students will design their flow-through apparatus and then using a permanent marker they will draw it on the Shrinky-Dink® sheet. *An alternate method* is for the students to design the device using PowerPoint and then print it with a laser printer on the film. Designs should be around 10 - 15 cm^2. Cut out the device leaving aobut 1 cm around it.
- Follow the instructions for heating the Shrinky-Dinks®. Place the design on a flat surface in a standard toaster oven for 3-5 minutes at 350^{O}F. The plastic will curl while shrinking. They will uncurl after complete shrinking. Continue to bake the Shrinky-Dink® for about 7 minutes after shrinking. The extra time helps the ink stick to the plastic. *An alternate* method proposed by Hemling et al (see resources) is to fill a 500mL beaker 1/3rd full of of vegetable oil and heat on a hotplate to 150^{o}C. Using tweezers, place film into the oil and leave until it curls and uncurls (~1 minute). Once completed, place between two glass plates and allow to cool.
- Students will be creating their devices using polydimethylsiloxane or PDMS. Mix according to instructions, typically the mix ratio is 10:1 - base to catalyst. Mix in cups using either a plastic spoon or a stirring stick. It will become white and cloudy with bubbles. Degas the mixture using a desiccator/vacuum system. It is recommended to degas the mixing cup for 10-15 minutes before pouring it into petri dish. Place the cut Shrinky-Dink® design (ink side up) in a plastic petri dish. Use double sided tape to hold it in place. Pour the PDMS mixture over the Shrinky-Dink® completely covering the design.

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Repeat the degassing procedure until all bubbles are eliminated (15-30 minutes). Allow the PDMS to cure at room temperature for 48 hours. *Alternative method* is to bake at 60°C for 2-3 hours or overnight.

- Have students wear gloves to remove the mold. They should GENTLY cut it away with a scalpel/razor blade and remove the mold from the petri dish. The PDMS should show a negative imprint of the pattern.
- Adhere the mold to a glass plate. For student purposes, double-stick tape should suffice.
- Using a blunt needle,probe, or biopsy punch, punch holes into the PDMS for inlets and outlets. The device is now ready for testing.

3. Wikki-Stix® with PDMS activity:

This activity falls between the JELL-O® macro scale and the Shrinky-Dink® micro scale.

- Students will design their pattern using the Wikki-Stix®. It must be small enough to fit into the petri dish.
- Press the design onto a plastic petri dish and anchor with double stick tape. Press gently to make sure there are no bubbles between the tape and the device.
- Mix PDMS (polydimethylsiloxane) according to instructions noted above in method 2. Degas as noted above.
- Pour the mixture over the Wikki-Stix® design. Degas again as noted in method 2 above. Allow the PDMS to cure at room temperature for 48 hours or bake at 60°C for 2-3 hours or overnight.
- Have students wear gloves. Using scalpel or razor blade cut the mold and gently remove it from the petri dish. The PDMS should show a negative imprint of the pattern after removing Wikki-Stix®.
- Using double sided tape, adhere the mold to a glass plate.
- Students may leave ends of the Wikki-Stix® exposed for holes and pull the Wikki-Stix carefully through the imprint in a snake-like fashion. If needed, holes can be punched into the PDMS for inlets and outlets. A blunt needle, probe, or biopsy punch will work.

Experimental variables:

You teacher will assign which fabrication method to use and what experimental variables are to be tested. Below is some of the variables that you might be asked to test. Can you think of other chemistry concepts you would like your device to perform?

- Test the viscosity of the devices using baby oil for a thick fluid compared to fruit juice.
- Use food coloring to demonstrate laminar flow. Requires two inlets. Use two syringes each containing a different color dye.
- Use glitter of various sizes to demonstrate particle size versus speed of flow. Put glitter into water and inject the fluid into an inlet.
- Mix two of more solutions to neutralize an acid or a base.

Record in your lab notebook:

- Variables to be tested
- Design of your device

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    - Including how it will be able to test your variables
- Your results
    - What was the outcome of your experiment?
- Ideas for improving your device

Analyze the Results:

1. **What is laminar flow?**
   Laminar flow is streamline flow in which the fluid flows in layers with no disruption of layers (no mixing).

2. **What is turbulent flow?**
   Turbulent flow in fluids creates eddies and chaotic motion in the fluid (mixing).

3. **How do pressure changes in a system affect velocity of flow?**
   As pressure increases within a system, flow velocity increases.

4. **What advantage is gained by the patient by faster response times in medicine?**
   Faster response times equates to faster diagnosis and treatment.

5. **What advantage is gained by the patient by using smaller sample sizes?**
   Smaller samples sizes will result in less blood/fluid volume needed for diagnosis.

6. **What is meant by the term viscosity?**
   Viscosity refers to the thickness of a fluid.

7. **What is the effect of the viscosity of a fluid on flow velocity?**
   Increasing viscosity of a fluid decreases the velocity of flow. Conversely, decreasing the viscosity of a fluid increases the velocity of flow.

8. How is nanotechnology impacting microfluidics?
   Answers will vary but should include increased number of tests with miniaturization, increased accuracy, faster analysis times.

Draw Conclusions:

- Discuss the scientific principles you learned with this activity.
- How did your experiment work? If it didn't work, why not?
- What were the independent and dependent variables of your experiment? What changes occurred and why?
- What were the benefits or limitations of the method you used?
- Do you think a different fabrication method would have improved your results?
- What are the real life applications of your experiment?

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Development and distribution funded by the **National Science Foundation**