Designing a Polymer Composite:

An Introduction to Polymers

N Y S C A T E
NEW YORK STATE CURRICULUM
for Advanced Technology Education
Integrated MST Design Activities for
High School and Community College Students

Partners in New York State Curriculum for Advanced Technology Education
Hofstra University
New York State Education Department

Project Co-Principal Investigators
Linda Hobart
Finger Lakes Community College

John E. Jablonski, Vice President and Dean of the College
Fulton-Montgomery Community College

Margarita Mayo, Director of Education, Training and Quality
New York State Business Council

Godfrey I. Nwoke, Ph.D.
New York City College of Technology

Jean Stevens, Assistant Commissioner, Office of Workforce Preparation and Continuing Education
New York State Education Department

Management Team

Project Co-Directors
M. David Burghardt, Ph.D.
Michael Hacker
Hofstra University

Project Coordinator
William Peruzzi, Ph.D.
Hofstra University

Project Administrative Assistant
Lois Miceli
Hofstra University

Project Advisory Council
Stuart Field (Chair), Manager, Saratoga Division
Slack Chemical Company

Dr. James C. Dawson, Member
N.Y.S. Board of Regents

Nancy Bryan, Past President
New York State Technology Education Association

James Cimino, Executive Director
Association of Career and Technical Education Administrators

Dr. Lorraine Hohenforst, Coordinator of Instructional Services
Hamilton-Fulton Montgomery BOCES

Dr. Elaine, A. Johnson, Director
Bio-Link (ATE) Center, City College of San Francisco

Dr. James V. Masi, Retired Executive Director, Northeast (ATE) Center for Telecommunications Technology
Professor Emeritus, Western New England College

Mr. Bernard McInerney, Statewide Tech Prep Coordinator
New York State Education Department

Mr. Gordon Snyder, Executive Director
National Center for Telecommunications Technology

Project Evaluation Team
Bert Flugman, Ph.D. Director
Deborah Hecht, Ph.D.
Center for Advanced Study in Education
City University of New York

Principal Writer: Robert Dayton
Contributing Author: Anne Paige
Consultant/Writer: Dorothy Rosenthal, Ed.D.

Copy Editor: Barbara L. Kelly
Publications Designer: Lesa Clark

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The University of the State of New York
The State Education Department

Introduction to Polymers

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I. INTRODUCTION AND OVERVIEW

ABSTRACT

This module features the integration of mathematics, science, and technology (MST) through an emphasis on informed design in the field of polymer products. In response to a challenge, groups of students consider specifications and work within constraints as they design, construct, and test a new composite polymer material to be used for a recreational product line.

In meeting the challenge, students acquire understandings of the structure and function of the organic molecules that make up polymers and the properties that make polymers the right choice for a specific application. The students perform a series of Knowledge and Skill Builder activities (KSBs) to prepare them for the informed design process. These activities enable students to use knowledge and skills rather than trial and error alone in designing their polymer products. The KSBs include: a study of the chemistry of polymer synthesis; research focusing on natural and synthetic polymers; activities designed to test materials for their polymer layers; and an investigation of the glues and adhesives used to make the composite.

GRADE LEVEL: 11–12

TIME ALLOCATION IN 45-MINUTE PERIODS: 21

EXISTING HIGH SCHOOL COURSES ENHANCED BY THE MODULE

- Regents Chemistry
- Local Chemistry
- Materials Science Technology
- Principles of Engineering

II. DESIGN CHALLENGE OVERVIEW

SETTING THE CONTEXT FOR STUDENTS

Introduction

You are part of the research and development unit for a large recreational equipment and supply company. Your group has been assigned the task of designing and testing a new polymer composite for use in one of the company's new products, a fully outfitted snowmobile.

Design Challenge

Design and test a composite of multiple layers of polymer material bonded together to form a material suitable for use in the body of the snowmobile, in the protective storage/transport shell, or in a matching snowmobile suit.

Specifications

Your group is to submit one sample of the polymer composite along with individual reports of test results to support claims that this composite is suitable for the intended application on the snowmobile.

Constraints

The composite must have a minimum of five layers, must include at least one synthetic and one natural polymer layer. The adhesive(s) and coating(s) may be natural and/or synthetic and are not considered layers. If you decide on a polymer, glue, or adhesive not tested as part of the KSBs, then you must justify its use through other test results. Then you can include it or them in your composite. The sample your group produces is to be 10 cm x 30 cm ± 0.5 cm.

Thickness requirements are:

- Snowmobile body material – 0.5 cm
- Snowmobile storage/transport shell – 1.0 cm
- Snowmobile suit – 2.0 cm

The sample may be less than the maximum thickness.
Each composite should be waterproof or highly water-resistant.
The composite's flexibility should be appropriate for the intended use.

Sources

1. American Chemical Society. (2000). Polymer Research and Development (Science in a Technical World Series, pp. 19–25, 49–51). New York: W.H. Freeman & Company.
2. American Chemical Society. (2000). Chemistry in the Community (4th ed.). New York: W.H. Freeman & Company.
3. Hands on Plastics Kit (American Plastics Council).
4. Heikkinen, H., Orna, M.V., & Schreck, J.O. (Eds.). (1994). SourceBook (Version 2.1, Volume 3). Philadelphia: Chemical Heritage Foundation.

III. GOALS AND LEARNING OUTCOMES

The learnings promoted by *Introduction to Polymers* are listed below; the order in which they appear is based on the order of the learning standards for mathematics, science, and technology (MST) for New York State. (The NYS MST learning standards most closely addressed by each outcome are indicated in parentheses.)

In *Polymers*, students apply the process of informed design. To do so, they must acquire the following MST standards-based knowledge and skills:

- how to carry on informed design (NYS MST Learning Standard 1)
- how to conduct controlled experiments (NYS MST Learning Standard 1)
- graphing techniques and interpretation (NYS MST Learning Standard 2)
- linear and nonlinear relationships (NYS MST Learning Standard 3)

After completing this module, students have the following major understandings and skills, found in the New York State Chemistry Core Curriculum:

- Classify an organic compound on the basis of its structural or condensed structural formula.
- Draw a structural formula with the functional group(s) on a straight-chain hydrocarbon backbone, when given the IUPAC name for the compound.
- Draw structural formulas for alkanes, alkenes, and alkynes containing a maximum of ten carbon atoms.
- Apply the adage “like dissolves like” to real-world situations.
- Identify types of chemical reactions.
- Identify organic reactions.
- Distinguish between nonpolar covalent bonds (two of the same nonmetals) and polar covalent bonds.
- Relate that organic compounds contain carbon atoms that bond to one another in chains, rings, and networks to form a variety of structures. Organic compounds can be named using the IUPAC system.
- Relate that hydrocarbons are compounds that contain only carbon and hydrogen. Saturated hydrocarbons contain only single carbon-carbon bonds. Unsaturated hydrocarbons contain at least one multiple carbon-carbon bond.
- Relate that organic acids, alcohols, esters, aldehydes, ketones, ethers, halides, amines, amides, and amino acids are categories of organic molecules that differ in their structure. Functional groups impart distinctive physical and chemical properties to organic compounds.
- Relate that isomers of organic compounds have the same molecular formula but different structures and properties.
- Relate that, in a multiple covalent bond, more than one pair of electrons are shared between two atoms.
- Relate that unsaturated organic compounds contain at least one double or triple bond.

- Relate that types of organic reactions include: addition, substitution, polymerization, and esterification.

In this module the teacher:

- prompts acquisition of mathematical analysis, scientific inquiry, and informed design processes (NYS MST Standard 1);
- fosters cooperative learning as students work in design teams (NYS MST Standard 1);
- provides opportunities for improving communication skills through the use of the Design Journal; Design Report; and group presentation (NYS MST Standard 2);
- introduces students to the informed design process through an engaging Design Challenge (NYS MST Standard 1);
- involves individuals and groups as they compose, construct, test, improve, and present their design solutions (NYS MST Standard 1);
- provides opportunities to hone ideas through reasoning, library research, and discussion with others, including experts; for example, students locate data from published sources to support/defend/explain patterns observed in natural phenomena (NYS MST Standard 1);
- encourages students to refine research ideas through library investigations, including information retrieval and reviews of the literature, and through peer feedback obtained from review and discussion (NYS MST Standard 1);
- helps students realize what they already know about polymers and about design (NYS MST Standard 4);
- guides students as they identify and investigate factors relevant to design performance (NYS MST Standard 1); and
- facilitates acquisition of mathematical, scientific, and technological principles related to polymers (NYS MST Standards 3–5).

In the Additional Support for Teachers section, pages 46–56, there is a subsection devoted to related learning standards, including standards other than the MST learning standards for New York State.

IV. TIMELINE CHART

The suggested order for completion of KSBs by students is:

1. Comprehend the Design Challenge Overview Handout.
2. Complete KSBs.
3. Produce and test the composite material.
4. Develop group presentation and submit individual Design Report.
5. Make group presentation to class.

NOTE: There are two types of KSBs. Those that relate primarily to technology education have a *T* in front of the number and those that relate primarily to science have an *S*.

PERIOD	FOCUS MODEL COMPONENT (for Teacher)	INFORMED DESIGN LOOP COMPONENT (for Student)	ACTIVITY
1	Focus Discussion on Problem Context	Clarify Design Specifications and Constraints	Begin discussion of the Design Challenge Overview Handout 1.
2–3	Organize for Informed Design		Discuss KSB T1: The Informed Design Loop; finish overview. Complete KSB T2: Keeping a Design Journal.
4–17	Coordinate Student Progress	Research and Investigation	Complete KSB S1: Monomers to Polymers. Complete KSB S2: Researching Polymers. Complete KSB S3: Identifying Polymers from Their Properties. Complete KSB S4: Thermoplastic and Thermoset Polymers. Complete KSB S5: Preparation and Properties of a Cross-Linking Polymer. Complete KSB S6: Which Polymers "Hold" Water? Complete KSB T3: Impact Effects: "Dropped Dart Tests." Complete KSB T4: Glue: Holding It All Together.
		Generate Alternative Designs	Consider design options based on research and investigation.
		Choose and Justify Optimal Design	Develop design for composite and design methods for testing composite.
		Develop a Prototype	Produce composite material.
		Test and Evaluate the Prototype	Test and evaluate the composite.
18–19	Unite Class in Thinking About What Has Been Accomplished	Redesign	Make class presentations of methods and results. Submit reports.
20–21	Sum Up Progress on Learning Goals		Review learning goals. Practice constructive assessment.

V. MATERIALS, SAFETY CONSIDERATIONS, AND RESOURCES

Materials

Lists of materials are included in the separate teacher sheets for each KSB. Below is a list of suggested materials for the Design Challenge.

- Polymer materials (both natural and synthetic) from commonly available sources: home, home improvement stores, etc.

SYNTHETIC

Saran™ Wrap	plastic grocery bags
Dry cleaning bags	freezer bags
foam board	Styrofoam™: meat trays, cups, egg cartons
fabrics	packing peanuts
bubble wrap	nylon string/cord
tapes: Scotch™, packing, duct	Plexiglas™
drinking straws	plastic pipettes
Great Stuff foam	other samples of recyclables 1–7

NATURAL

balsa and other woods	cotton/wool string/yarn
natural fibers/fabrics	starch packing peanuts
cardboard	paper
latex sheeting	

ADHESIVES AND RESINS
Glue: Elmer's, wood glue, epoxy glue, silicone and other caulks, putty, rubber cement, contact adhesive
"Slime," "Gluep" (students will make these later in a KSB)

COATINGS

Scotchgard™	paint
varnish	shellac

If you allow students to bring in other materials, have them get permission from you prior to bringing the materials to school and also before using them in school. Approve materials based on flammability and other safety concerns.

- Tools for cutting: knives, saws, razor cutters, etc.

Safety Considerations

Working in the laboratory requires care and responsibility. Designing and constructing using polymers and adhesives can involve exposure to harmful vapors and concerns about flammability. Motivate all of the students to participate in a teacher-led group activity focusing on safety for the *Polymers* module. Include as many as possible of the safety procedures that apply to work in a chemistry laboratory. Safety information is present also in the Additional Support for Teachers section; see “Recommendations for Safe Laboratory Practices,” page 47. Students are expected to continue to follow all standard safety procedures throughout the module. The classroom teacher must address proper ventilation and related procedures to deal with risks, and must manage the laboratory so that all groups are working on the same action during the period to minimize the number of exposures to risks (e.g., vapors and flames). Within the student handouts, specific safety concerns are addressed. Look for the specific safety statements where applicable.

Resources

Access to computers that are Internet-connected
Selected Internet sites:

Macrogalleria	http://www.psrc.usm.edu/macrog/index.htm
Polymer information	http://www.polymerprocessing.com/polymers/index.html
SPE Outreach	http://www.4spe.org/trainingeducation/communityoutreach.htm
Polymer Ambassadors	http://www.uwsp.edu/chemistry/ipec/pa/
American Plastics Council	http://www.americanplasticscouncil.org/
Modern Plastics	http://www.modplas.com/
National Plastics Center and Museum	http://npcm.plastics.com/
Assoc. of Plastics Manufacturers in Europe	http://www.apme.org/dashboard/dashboard.asp?bhcp=1
Hands-on Plastics	http://www.handsonplastics.com/
Plastics.com	http://www.plastics.com/
Plastics in the Automobile Industry	http://polymerics.tripod.com/index2.htm

To Be Ordered for Arrival Before Start of module

Videos clips: “Better Surfboards” and “Carbon Fiber Composites” from *ChemWorld* CD-ROM, Vanderbilt University, May 1997. The ChemWorld CD-ROM set may be obtained from Dr. Melvin Joesten of Vanderbilt University. Contact him at Melvin.d.joesten@vanderbilt.edu. He will provide a CD set free of charge to teachers for use with this module. Provide information indicating the name of the module, your name and mailing address, and your teaching assignment.

VI. PROCEDURAL SUGGESTIONS

PEDAGOGICAL FRAMEWORK, THE FOCUS MODEL, AND KSBs

A separate document, the NYSCATE *Pedagogical Framework* (see www.nyscate.net), provides an in-depth understanding of the NYSCATE challenge statements (p. 6), the FOCUS pedagogical model for teachers (p. 7), Knowledge and Skill Builders (KSBs) to inform student design (p. 6), the informed design loop for students (p. 10), and more. Teacher tips for coordinating student work on the KSBs are found starting on page 13.

Here suggested strategies are presented within the context of the NYSCATE FOCUS on Informed Design pedagogical model for teachers. The FOCUS components are: Focus discussion on the problem context, Organize for informed design, Coordinate student progress, Unite the class in thinking about what has been accomplished, and Sum up progress on the learning goals (see NYSCATE *Pedagogical Framework* for more on this model).

- Copy and distribute the Design Challenge Overview Handout (see Student Handout section).

Focusing discussion on the problem context

The problem: In order to focus and engage your students, relate to them that their group, which is part of a large recreational equipment company, has been assigned the task of designing and testing a new polymer composite for use in one of the company's new products.

After providing "wait time" for the class to think, elicit, record (on chalkboard, flip chart, or overhead projector) and discuss ideas for the meaning of *polymer composite*.

Show and discuss the video clips "Better Surfboards" and "Carbon Fiber Composites" from *ChemWorld* CD-ROM, Vanderbilt University, May 1997.

DESIGN CHALLENGE OVERVIEW HANDOUT

Your group is part of the research and development unit for a large recreational equipment and supply company. Your group has been assigned the task of designing and testing a new polymer composite for use in one of the company's new products, a fully outfitted snowmobile.

Design Challenge
Design and test a composite of multiple layers of polymer material bonded together to form a material suitable for use in the body of the snowmobile, in the protective storage/transport shell, or in a matching snowmobile suit.

Specifications
Your group will submit one sample of the polymer composite along with individual reports of test results to support claims that this composite is suitable for the intended application on the snowmobile.

Constraints
The composite must have a minimum of five layers and it must use at least one synthetic and one natural polymer. The adhesive(s) and coating(s) may be natural and/or synthetic and are not considered layers. If you decide on a polymer, glue, or adhesive not tested in the KSBs, then you must justify its use with test results before using it in your composite. The sample is to be 10 cm x 30 cm ± 0.5 cm.

Thickness requirements are:

- Snowmobile body material – 0.5 cm
- Snowmobile storage/transport shell – 1.0 cm
- Snowmobile suit – 2.0 cm

The sample may be less than the maximum thickness.
Each composite should be waterproof or highly water-resistant.
The composite's flexibility should be appropriate for the

Tell the groups that they are to focus on the concepts of polymer formation, polymer properties, polymer testing, and adhesives that bond polymer layers together. Describe the Design Challenge in general terms.

Refer students to copies of the Design Challenge Overview Handout as you and they discuss the challenge.

Display for the class a section of a ski to show the layers of material that make up a ski. Usually a ski has a decorative top layer; a core, which may be wood; and a bottom layer, which is usually polyethylene. (You may be able to obtain a broken ski from a ski shop.) Ask "KWL" questions such as the following to find out what the students <u>know</u>, what they <u>want to know</u>, and what they need to <u>learn</u>: "Why is polyethylene used as food packaging but polyurethane is used in refrigerator insulation?" and "Why do some products contain polymers that are rigid and some that are very flexible?" “Why do some contain both?” Use questions similar to these here and elsewhere to discover the naïve conceptions individual students hold about polymers and composites used in real-world applications.

The challenge: Redirect students to the Design Challenge Overview Handout. Review the contents together. Discuss the challenge in more detail. Discuss briefly the Here’s What You Will Do, Problem Context, and Materials Needed sections.

Organizing for Informed Design

The Design Challenge has been introduced to the students, who should be aware of the goals of the project and have the motivation to be successful. The students should now be ready to begin the ten KSBs that will help them develop informed designs to address the Design Challenge.

Assigning groups: Talk with some of the students ahead of time to see how experienced they are at working in cooperative groups. Assign small working groups (three students per group is ideal). (See p. 11, “Forming and Facilitating Design Teams,” in the *Pedagogical Framework*.) Monitor groups throughout the module.

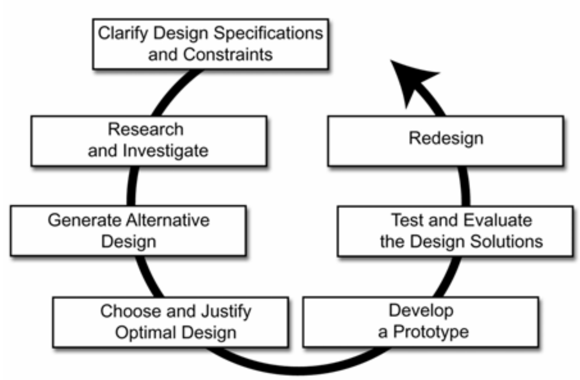
- Copy and distribute copies of KSB: T1: The Informed Design Loop.

The students should be in their design teams for the KSBs. Assist the teams as they discuss and formulate responses to the questions in this KSB.

Informed design: (See the NYSCATE *Pedagogical Framework* for a more detailed discussion on focusing students

KSB T1: The Informed Design Loop

The informed design loop (see diagram below) is a method to achieve informed technological design based on knowledge and skills, rather than on trial and error alone. The loop involves repeatable phases that engage you in the design process and that can be repeated many times to improve your design.



on the process of informed design.) Elicit from students what they know about good design and who engages in design. Ask for examples of good design and poor design.

Coordinating student progress

Coordinate work by individuals: Plan opportunities within this module for students to revisit their initial understandings by providing experiences with new phenomena that contradict their stated perceptions. Unless individuals get to actively process such contradictions, they will likely fail to grasp the new concepts and then may revert to their preconceptions.

Help individual students make the connection between carefully documenting information as they proceed and well-written reports and presentations at the end.

Note that a student displaying unacceptable behavior may be doing so because other members of the group do not value what the student says. Get to know the strengths of such a student and try assigning roles for all members of his or her group. Give the student a role that features a personal strength and inform the group ahead of time that this person is known to do that task well.

As the work becomes more technical and cerebral, some students will begin to complain that they are doing all the work while others loaf. Citing examples from your own experience, explain to such individuals that the best way to learn something is to teach it to others. Remind the group that it is essential that all members of a cooperative group understand all ideas and steps along the way. Conduct frequent oral checks to see that each student has adequate understanding before the group moves on in its work.

Group research and investigation through KSBs: Facilitate the student work on the science KSBs, starting with KSB S1: Monomers to Polymers. Individual procedural sheets for the KSBs are found in the Student Handout section.
Tell the class that completing a series of KSBs will help prepare them for addressing the Design Challenge they face. Then introduce the first KSB (KSB T1: The Informed Design Loop), and provide time for students to read it. Refer to the information in KSB T1 often as groups work on the Design Challenge. The informed design loop can be particularly useful to the students as they chart their progress using a design; like professional engineers, they will find themselves using the loop in an iterative way rather than in a linear way.

Discuss the informed design loop and stress that although design is normally informed by the designer's current knowledge, completion typically requires access to new knowledge. Discuss the need to research what solutions exist to solve this Design Challenge, and consider how reaching an optimal design solution requires meeting specifications, working within constraints, and making trade-offs.

Student requirements: Discuss the student requirements for the module. A sample letter from a recreation equipment company is included in the Additional Support for Teachers section. Help students see that their Design Journal is where they document progress as they complete literature searches, factor investigations, and Knowledge and Skill Builders (KSBs). Describe the requirements that each student submit a Design Report and each group make a class presentation at the conclusion of the module. Explain that the report and the presentation will be based on information recorded in the Design Journal. Alert students that the presentations should be multimedia and should detail their design process and results. Help them see that such a presentation summarizes work completed in researching, collecting, and analyzing data; developing models; improving designs; and making refinements. Describe multiple forms of media (e.g., posters, presentation software, color overheads, videos, computer animation, website) that they might use to enhance their presentations. Assure them that when classmates ask probing questions and challenge group findings at the end of presentations, they are mirroring proceedings that are common at science conferences.

Responses to Questions

1. Responses will vary. Monitor the extent of the responses to see that the group has developed a reasonable defense for any changes they have made to the informed design loop.
2. Responses will vary. Look for reasons related to design flaws in the product or process chosen by the group. Look for the explanation of the consequences of the design flaws. Also, the group should have chosen an additional product or process that could benefit from improved design.

Once the groups have completed the questions in KSB T1, conduct a class discussion in which groups share their responses and ideas.

KSB T2: Keeping a Design Journal

A Design Journal is a complete, permanent record of what you do each day as you work—it is a record of your activities and thinking. For scientists, engineers, and technicians, the lab notebook is a history of work that can be referred to if they need to replicate their work or prepare a report to explain their work to others. It is also a legal document used to support applications for patents or provide evidence of all laboratory tests for a company.

Your Design Journal should be neat, accurate, and written in pen. Pages should be dated so that it is easy to follow the order of your work. The lab notebook is necessary every time you work on the project. You are responsible for keeping your lab notebook in a safe and secure place so that it is available for each class period. Even though you may be working in a team, you should keep your own notebook containing a record of all:

- Predictions
- Tests and procedures, including equipment and supplies used
- Data: specific observations and accurate measurements with units
- Illustrations
- Observations
- Data analyses including graphs, charts, and calculations
- Notes
- Conclusions

At the end of each class period, remember that you need to have your Design Journal witnessed and signed off by another member of your team!

DJ – This icon will be displayed throughout the KSBs to indicate when to record information in your Design Journal. You may enter information

- Copy and distribute KSB T2: Keeping a Design Journal. This will guide them in setting up a journal notebook. The Design Journal is a model for the method of recording information used in real-world laboratory work. It is very important that the students understand this model as a “job skill.”

Students need a bound notebook to use as their Design Journal. This could be a small spiral notebook or composition book, or other similar notebook. Each student’s Design Journal should be labeled with his or her name and any other identifying information you would like.

As you work through the KSB sheet with the students, emphasize important facets of the Design Journal that will improve their ability to produce a successful design and that will be important in the evaluation of the journal.

Be sure students understand the meaning of the icon **DJ** to be found in the KSB activity sheets. Also, emphasize the importance of having the Design Journal signed at the end of each day’s work.

Here are some examples of activities that can be used to give the students an experience with the informed design loop. Also, students will be able to construct different types of data/observation entries in their Design Journal.

1. “Learning by Process” activity
   Think of three or four tasks, activities, or processes that you have learned. Name the task/activity/process you learned and tell how you learned it. Describe the process.

2. “Map to House” activity (diagramming, labeling, giving directions)
   To the student: “You are inviting a friend to your house after school. You need to give your friend a map *and* written directions from school to your house. Be sure that the map is well labeled and the written directions are detailed.”

3. “Plumber’s Tape” (Teflon tape) activity (stretching, breaking, distorting words) This activity involves learning to work with a partner or in a team to enter data, organize materials, and make predictions, all while working with a polymer.

Evaluate and discuss each of the examples of data/observations given in the KSB sheet. Point out that these are examples and students may devise other methods of displaying data and observations in their Design Journal.

Responses to Questions

1. [Examples of student-generated “learning by process” ideas]
2. [Examples of student work in the “map to house” activity]
3. [Examples of responses to the ”plumber’s tape” activity]

- Copy and distribute KSB S1: Monomers to Polymers.

Expected Student Background

Students should have a basic understanding of atoms and elements. Also, they should know that atoms of elements may bond to each other to form compounds.

Core Concepts and Skills

Standard 4

- Draw a structural formula with the functional group(s) on a straight-chain hydrocarbon backbone, when given the IUPAC name for the compound.
- Draw structural formulas for alkanes, alkenes, and alkynes containing a maximum of ten carbon atoms.
- Identify organic reactions.
- Organic compounds contain carbon atoms that bond to one another in chains, rings, and networks to form a variety of structures. Organic compounds can be named using the IUPAC system.
- Hydrocarbons are compounds that contain only carbon and hydrogen. Saturated hydrocarbons contain only single carbon-carbon bonds. Unsaturated hydrocarbons contain at least one multiple carbon-carbon bond.
- Organic acids, alcohols, esters, aldehydes, ketones, ethers, halides, amines, amides, and amino acids are categories of organic molecules that differ in their structures. Functional groups impart distinctive physical and chemical properties to organic compounds.
- Isomers of organic compounds have the same molecular formula but different structures and properties.
- In a multiple covalent bond, more than one pair of electrons are shared between two atoms.

KSB S1: Monomers to Polymers

Polymers are long-chain molecules made up of repeating smaller chemical units **(monomers).** In this KSB you will create and manipulate molecules to form

The BIG SIX recyclables. *Plastics are made up of building blocks called monomers, derived from petroleum or natural gas; therefore, the human-made plastics are called* synthetic *polymers. The monomers are chemically linked to form chains called polymers, or resins. Different combinations of monomers yield resins with special properties and characteristics. Six resins account for 97% of all plastic bottles and containers.*

DJ – This icon will be displayed throughout the KSB to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

__**Part I: Recyclables 2 and 4**__

Step 1. From your pattern page, cut out:
  Two carbon blocks
  Four hydrogen blocks
  One sigma bond
  One pi bond

Save the rest of your pattern page for use in further activities.

A carbon atom has four valence electrons and, therefore, will form four covalent bonds. Attach the two carbon atoms with a sigma bond and a pi bond. Place one hydrogen at the top and bottom of each carbon atom and attach with adhesive poster-hanging putty (e.g., Fun-Tak^{TM}).

You have now created a model of **ethene** (**ethylene** is the common name). Draw your molecule model here. **DJ**

Notice that your sigma bond is thicker than your pi bond. Sigma bonds are stronger because there is a greater overlap of electron orbitals and the overlap is along the bond axis. Pi bonds are weaker because there is less orbital overlap and the overlap is perpendicular to the bond axis.

Step 2. Remove your pi bond that holds the carbon atoms together and slide your monomer next to that of the partner to your right. Link your monomer to his or hers with your Pi bond…Continue this linking

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- Unsaturated organic compounds contain at least one double or triple bond.
- Types of organic reactions include: addition, substitution, polymerization, esterification.

Standard 1 – Develop cooperative learning skills as students work in design teams.

Standards 3–5 – Acquire mathematical, scientific, and technological principles related to polymers.

Time: 1 period

Safety Considerations

Remind students to follow all standard safety procedures while working on this activity and not to run with scissors. See also Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47.

Materials / Preparation

Duplicate enough of the two pattern pages (using a separate sheet of paper for each page) so each student has copies of the sheets.

Materials: scissors for all students, adhesive poster-hanging putty (e.g., Fun-Tak^{TM}), colored markers (optional)

Hint: You can highlight the outline of the atoms/atom groups to make them more visible.

Hint: This activity can be expanded to include modeling alkanes, alkenes, and alkynes.

Hint: You may want to have students draw structural formulas in the handout or the design journal or both. Students will need directions about this before working on the KSB.

Responses to Questions

Monitor work in the Design Journals to see that the students have drawings and structural formulas for the different parts of the KSB.

H H H H H

C C H C

H

Sigma

Cl

Sigma

Sigma

Pi Pi

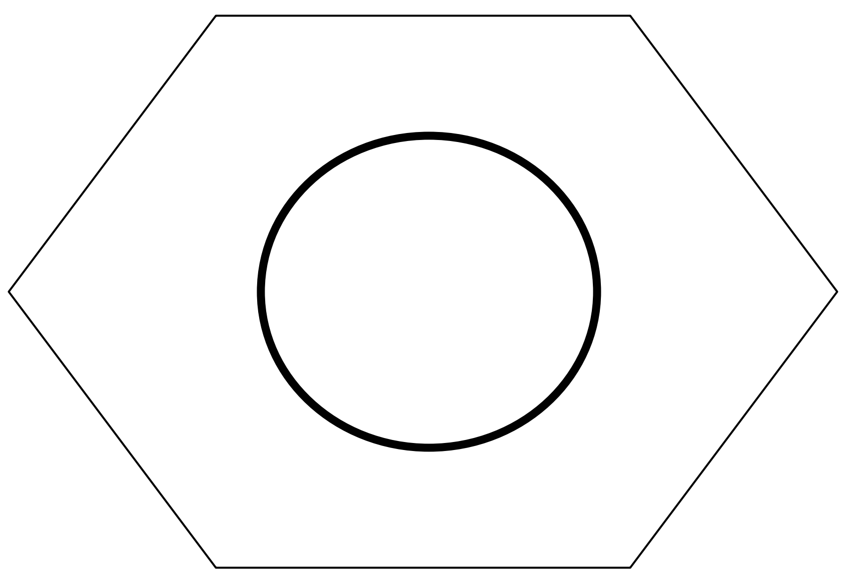
Sigma

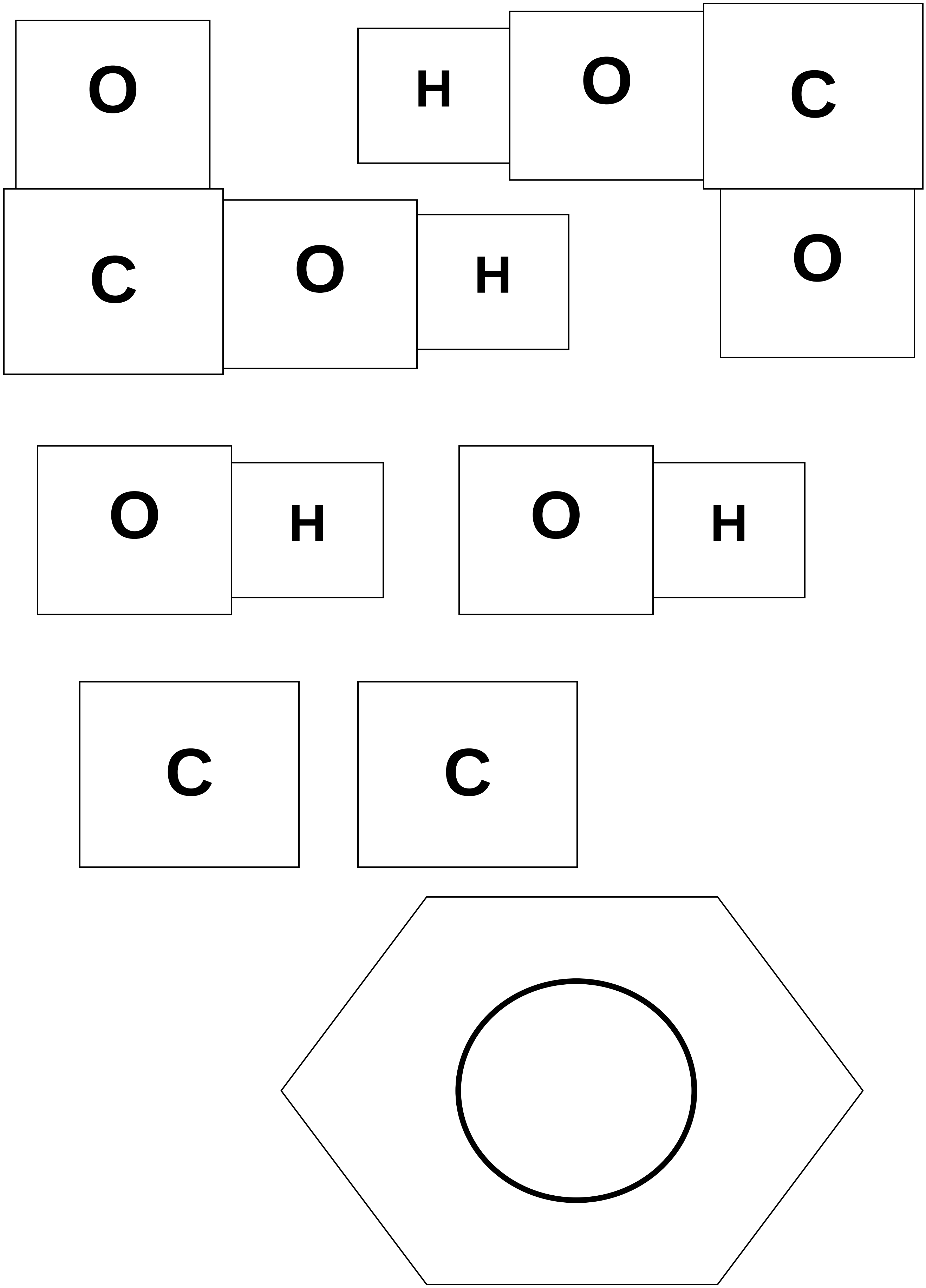
Pi Pi

Pi

Sigma

C

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- Copy and distribute KSB S2: Researching Polymers.

Expected Student Background

Students should have completed KSB S1: Monomers to Polymers. They should be familiar with the names, structure, and recycling symbols for several polymers.

Core Concepts and Skills

Standard 1

- Hone ideas through reasoning, library research, and discussion with others, including experts; e.g., locate data from published sources to support/defend/explain patterns observed in natural phenomena.

> **KSB S2: Researching Polymers**
>
> In this activity you and students from other working groups will become "experts" in one aspect of polymers by researching a topic and preparing to share your "expertise" with your working group. This type of activity is called a "jigsaw" because you will work together with your group to put all the information pieces together.
>
> Use the World Wide Web and printed materials to investigate your assigned topic about polymers. There will be a vast amount of information about polymers, so you should make a quick evaluation of each source to determine if it contains something of value before spending a great deal of time on a source that has little about your topic. When you decide to use information from a source, it is important that you record the source reference (URL, periodical issue and page, book bibliographical information, etc.). This will be useful later when you need to justify your choices for the polymers you use in your composite.
>
> **DJ** – This icon will be displayed throughout the KSB to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.
>
> **Topics to Research: DJ**
> (The following questions are given as guide questions; research should not be limited to these ideas.)
> .
>
> **History of synthetic polymers**
>
> 1. Find anecdotal events that led to the discovery of certain polymers.
> 2. Become familiar with scientists and their discoveries in polymer chemistry.
> 3. What events led to the discovery of different polymers?
> 4.
> 5.

- Refine research ideas through library investigations, including information retrieval and reviews of the literature, and through peer feedback obtained from review and discussion.

Standards 3–5 – Acquire mathematical, scientific, and technological principles related to polymers.

Time: 1 period

Safety Considerations: none

Materials/Preparation

This activity is to be set up as a "jigsaw," an activity in which individual students become "experts" in one aspect of polymers. Once the students are satisfied they have gathered the information necessary, they report to their working group, sharing what they have learned.

Make arrangements for access to computers that are Internet-connected. Arrange for groups to visit the school library or other reference areas. Books and periodicals can be brought to the classroom for use as well.

As the students work, monitor the information they are gathering on the basis of the guidance on the KSB sheet. Encourage them to extend the list for each topic as suggested by the extension of the numbered headings on the KSB sheet.
Once the information is gathered, organize the groups so that the experts disseminate the information to the other members of their working group. To complete the activity, encourage groups to discuss how this information connects to the Design Challenge and record important points from their discussion in their Design Journal.

Responses to Questions

The students should have the information they gathered to become "experts" in one aspect of polymers. They should also have the information gathered by the other "experts" in their working group. Finally, there should be a concluding entry in their Design Journal connecting this research to the Design Challenge.

- Copy and distribute KSB S3: Identifying Polymers from Their Properties.

Expected Student Background

Students should have completed KSBs S1 and S2 before working on this KSB. They should have a general knowledge of polymer formation and structure, along with an understanding of the sources and uses of many polymer substances.

Core Concepts and Skills

Standard 1 – Analysis, Inquiry, and Design
Observations made while testing provide new insights into phenomena.

- Represent and organize observations and interpret data.
- Develop a written report that describes proposed explanations.

Standards 3–5 – Helps students realize what they already know about polymers and about design (NYS MST Standards 3–5); guides students as they identify and investigate factors relevant to design performance (NYS MST Standards 3–5); and facilitates acquisition of mathematical, scientific, and technological principles related to polymers.

KSB S3: Identifying Polymers from Their Properties

The various models you made in KSB S1 show that polymers are small chains of repeating molecules called **monomers.** An entire polymer is referred to as a **macromolecule.** The properties of a particular polymer (and materials made from it) depend on both the properties of its monomers and the ways in which those monomers are linked together. Any structural change in the polymer or its monomers can result in significant changes in the chemical and/or physical properties of the polymer.

Polymers can be identified from their properties. One important skill you will need is to observe and measure the properties of polymeric materials (materials made from polymers).

Plastics are one very well known group of polymeric materials. In this KSB you will observe the properties of six plastics, and learn to relate their properties to the molecular structure of their constituent polymers. You will also learn to match the plastics with their resin, or recycling, code on products.

DJ – This icon will be displayed throughout the KSB to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Safety:

- Wear safety goggles and a laboratory apron at all times when in the laboratory. Also, secure long hair and any loose articles of clothing or jewelry. (These safety precautions apply to *all* polymer laboratory work you do.)
- Keep isopropyl alcohol, acetone, and corn oil away from open flames.
- Use forceps when placing a sample in a liquid for testing.
- Wash your hands after completing an activity.

Time: 2 periods

Safety Considerations

Remind students to wear safety goggles and a laboratory apron at all times when in the laboratory and to secure long hair and any loose articles of clothing or jewelry. These safety precautions apply to *all* polymer laboratory work they do. See also

Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47.

Isopropyl alcohol, acetone, and corn oil should be kept away from open flames. Students should avoid contact with these materials by using forceps to place samples in a liquid for testing and washing their hands thoroughly after completing an activity.

Materials / Preparation

6 plastic samples	Copper wire with heatproof holder
1 unknown plastic sample	Fume hood
Hot plate	Corn oil
Two 150-mL beakers	Isopropyl alcohol
Cardboard	Electronic balance
Forceps	100-mL graduated cylinder
Penny	Plastics Properties Flowchart
Stirring rod	Safety goggles
File	Laboratory apron
Candle or burner	Heatproof tray for wires
Ice water	Metric ruler (possibly vernier calipers)
Acetone	Design Journal

For the samples of polymers, provide small, irregular pieces of each polymer. Also, provide larger samples, both irregular- and regular-shaped, for the quantitative density measurements. Cardboard pieces need to be cut from boxes. Make pieces large enough to hold all samples for the scratch test.

Assemble the copper wire testers from small corks and 15-cm pieces of medium- to heavy-gauge copper wire. The wire can be inserted into the corks. Do not push the wire all the way through the cork. Check burners to see that they are working properly before the activity. If necessary, instruct students in the safe use of burners. The flame testing should be done in the hood to avoid exposure to the fumes produced when the plastics burn.

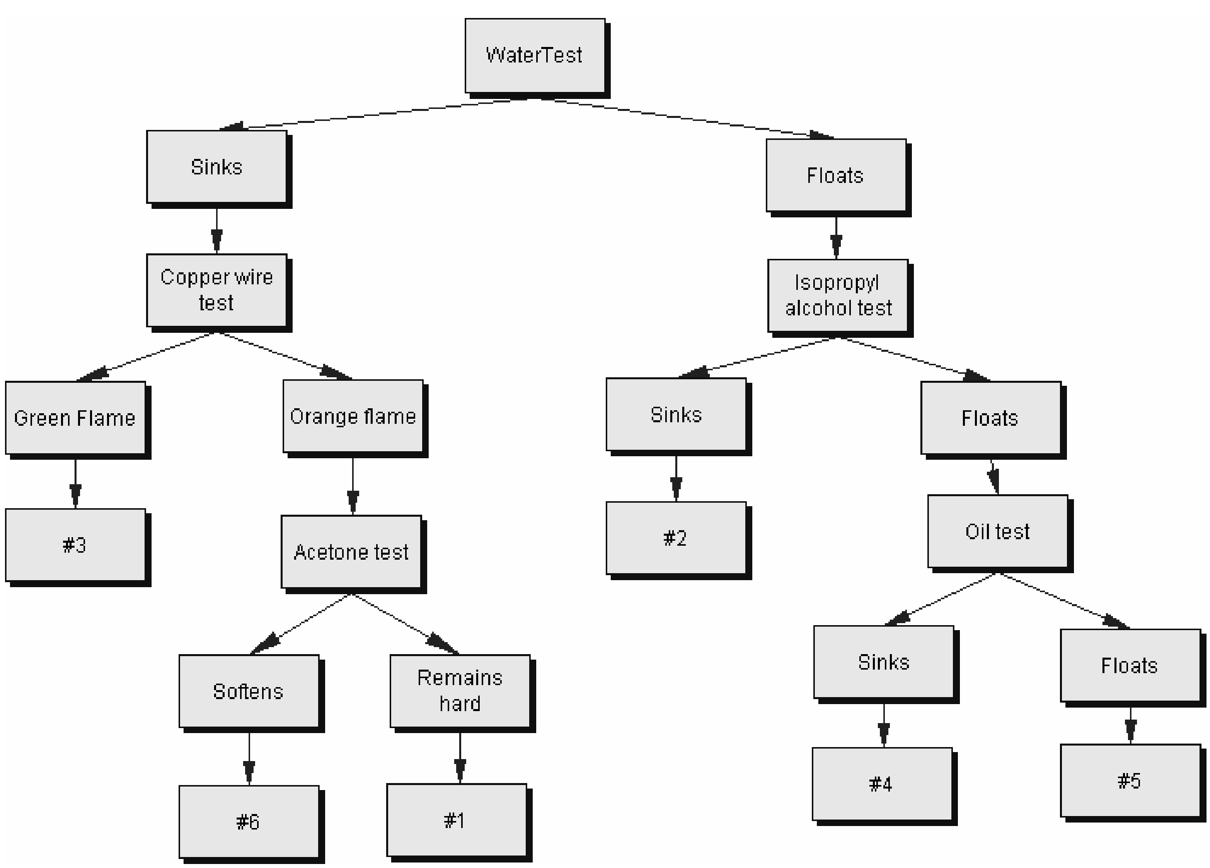
For the acetone test, provide a small shallow glass container. A 25-mL or 50-mL beaker works well. This test should be done in the ventilation hood due to fumes and fire risk. The samples are placed in the container and covered with a small amount of acetone. The samples should soak in the acetone for 5–10 minutes. The only polymer sample that should soften in the acetone is polystyrene; try to dent or scratch the sample with your fingernail to test this. The PET (polyethylene terephthalate) should remain hard. Also, the students should use forceps to avoid contact with the acetone when removing the samples. Provide a waste container in the hood, where the used acetone can evaporate.

Provide containers of the isopropyl alcohol and corn oil for the qualitative density tests. The isopropyl alcohol should be tested prior to the activity to verify its density. (The polypropylene [PP] and low-density polyethylene [LDPE] should float and high-density polyethylene [HDPE] should sink.) The alcohol solution can be adjusted by adding water or pure 2-propanol to get the desired results with polymer samples (recyclable #2 sinks and #4 and #5 should float). If you want separate containers for the used liquids, label containers for returned alcohol and oil and collect this for disposal or storage.

For the quantitative measurement of density, make assignments to each group. They may be assigned a regular- or irregular-shaped piece of polymer. If the regular-shaped piece is thin, provide vernier calipers for measuring the thickness. You may need to train the students to use the calipers. Irregular samples should be sized to fit into a 100-mL graduated cylinder with room to see a volume-level change when added to the 30 mL of water.

Assist students with their conclusions about the structures of the polymers. Refer them to the information in their Design Journals about the chemical formulas and possible physical arrangements of the polymer molecules.

Key to the flowchart for **KSB S3: Identifying Polymers from Their Properties**



2. Students should have a flowchart in their Design Journal that shows the steps they have taken to test the known polymer samples along with the results of the tests. They should also have a flowchart showing the steps and results for the tests on the unknown polymer sample.

3. Students should have recorded information relating the structure of the polymers to the properties tested in the activity.

4. Students should also have recorded the reasons individual polymers are chosen for specific applications.

The students should have a well-written conclusion that summarizes the testing, results, and connections to applications for the six (6) polymers in the activity.

- Copy and distribute KSB S4: Thermoplastic and Thermoset Polymers.

KSB S4: Thermoplastic and Thermoset Polymers

Two general types of polymers and their properties are:
Thermoplastic - Can be molded and remolded many times, using heat.
Thermoset - Once set, cannot be remolded.

Thermoplastic polymer chains are not connected to each other. They are only semi-crystalline or *amorphous*. Thermoset polymer chains have numerous cross-links that bond them into rigid networks. Their structure is much more crystalline.

Linear random coil | Branched polymer | Cross-linked polymer

The amount of intermolecular force is very different in the different polymers. The linear random coil has much less and the cross-linked polymer has much more. This is the primary difference between high-density polyethylene (HDPE) and low-density polyethylene (LDPE). (Note: You learned about these different polymers in KSB S1.)

You are to observe properties of a thermoplastic polymer, Friendly Plastic™, and a thermoset polymer, epoxy putty.

Expected Student Background

Students should know:
1. how polymers are formed from monomers.
2. the terms *thermoplastic* and *thermoset*.
3. how thermoplastics and thermosets differ in structure.
4. everyday examples of thermoplastics and thermosets.

The two general polymer types differ in properties because a thermoplastic polymer has only long, unconnected chains (randomly coiled), while a thermoset polymer has many cross-links, leading to a very rigid structure. Thermoplastic polymers can be heated and molded over and over again; thermoset polymers can be molded only once.
Polymer types are shown in Figure 1.

Linear random coil | Branched polymer | Cross-linked polymer

Core Concepts and Skills

Standard 1 – Analysis, Inquiry, and Design

Observations made while testing provide new insights into phenomena.
- Represent and organize observations and interpret data.
- Develop a written report that describes proposed explanations.

Standard 4 – The Physical Setting

- Classify an organic compound on the basis of its structural or condensed structural formula.
- Distinguish between nonpolar covalent bonds (two of the same nonmetals) and polar covalent bonds.
- Functional groups impart distinctive physical and chemical properties to organic compounds.

Time: 1 period

Safety Considerations

Read “Safety Considerations” in the student version of this KSB. See also Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47. Emphasize that students must *not* make bracelets or rings from these polymers, since the plastic will harden and become very difficult to remove. Also, students must *not* put any of the polymers in their mouths because it will stick to metal such as orthodontic braces. Provide rubbing alcohol to clean hands after using the epoxy putty. *CAUTION: Rubbing alcohol is flammable.*

Materials / Preparation (for 24 students working in pairs)

12 Sticks of Friendly Plastic™ (May be obtained in art supply stores or from AMACO Co., Indianapolis.)
12 Beakers, 400-mL
12 Burners or hot plates
1.5 Epoxy putty sticks (approximately 1.4 kg) or any similar product (found in the plumbing section of hardware stores)

Advance Preparation/Pre-Laboratory Discussion
Cut each epoxy putty stick into 1-inch-long pieces.
Review the structures of thermoplastic and thermoset polymers.

Responses to Questions: Teacher-Student Interaction

Thermoplastic Activity

1. Why is it necessary to heat Friendly Plastic™ in order to shape it? [*To give the polymer chains enough energy to slip and slide over one another.*]
2. Is this an exothermic or endothermic change? [*Endothermic.*]
3. Is this a physical or chemical change? [*Physical.*]
4. How many times can this material be remolded? [*Many times, as long as the polymer chains stay intact.*]
5. How could this material be used? [*In art sculptures and for temporary support of small objects in industrial molds.]*

Thermoset Activity

1. Why are the two epoxy putty components separated? [*To prevent premature reaction.*]
2. Why are the two components kneaded? [*Because the reaction will not take place without mixing the components.*]
3. As the epoxy putty sets, does it feel hot or cold? [*Hot.*]
4. Is this an exothermic or endothermic reaction? [*Exothermic.*] Is it a physical change or chemical reaction? [*Chemical reaction.*]
5. Could you remold this material if you do not like the first effort? Explain. [*No, this chemical reaction yields a rigid, new product by cross-linking.*]

Anticipated Student Results

Thermoplastic Activity

Students will be able to mold a piece of low-melting Friendly Plastic™, and discover that it can be molded repeatedly. They should be able to list a number of household items made from thermoplastic polymers, and conclude that thermoplastics are more easily recycled.

Thermoset Activity

Students will be able to mold a piece of epoxy putty and observe that it gives off heat as it sets. They should be able to draw a diagram of the cross-linking process. They should give examples of household items made from thermoset polymers. They should be able to predict what will happen when a thermoset polymer is placed in boiling water.

Responses to Data Analysis and Concept Development

1. Thermoplastics can be repeatedly molded, but thermosets cannot (see Figure 1 for molecular-scale models).
2. Items made of polyethylene, nylon, polyester, polyvinyl chloride, and polystyrene are thermoplastics. Examples include clothing and plastic packaging material such as bottles and bags. Thermosets are used in bowling balls, Formica™ tabletops, auto body parts, and kitchen utensils.

Responses to Implications and Applications

1. Thermoplastic polymers can be recycled; all that is necessary is to melt them again. (You should point out that polymers have to be *sorted*, however, and that the plastics industry has initiated a voluntary labeling program for all thermoplastics. See KSB S1 for plastic bottle codes.)
2. Where strength and heat resistance are important.
3. (a) Thermoset; (b) Thermoplastic; (c) Thermoplastic; (d) Thermoplastic; (e) Thermoset.

Post-Laboratory Activities

1. Students may have made jewelry items (pendants or earrings) from the Friendly Plastic™. Holes can easily be drilled in this material. Try drilling a hole

in a piece of Friendly Plastic™; compare with drilling a hole in epoxy putty. Is there any difference?
2. Both polymer types can be painted with acrylic paints or permanent colored markers.

Extensions

1. Test the flammability of a small piece of Friendly Plastic™. [*It is flammable, but it melts first.*]
2. Test the resistance of epoxy putty to a burner flame. [*It is nonflammable. It doesn't melt; it chars.*]
3. How does environmental temperature affect the epoxy putty's setting time?

NOTE: This is a good homework activity to test student observations. Have students observe the sample in a freezer, refrigerator, and incubator, and at room temperature. Also, try to set it under water.

Assessing Laboratory Learning

1. Draw "pictures in the mind" of how polymer chains in the Friendly Plastic™ look before and after being molded. Imagine spaghetti (see Figure 1).
2. Draw "pictures in the mind" of how the polymer chains in the epoxy putty might look, both before and after molding. Imagine "floppy" ladders (see Figure 1).

References

Thermoset polymer demonstration: Ferguson, Schmuckler, Caro, and Siegelman. (1973). *Laboratory Investigations in Chemistr*y, Teacher's edition. Silver Burdett. (Also contains information on variations in the activity.)
Epoxy molecular structure: *Encyclopedia of Science and Technology, Vol. 10*. (1974). New York: McGraw-Hill.

- Copy and distribute KSB S5: Preparation and Properties of a Cross-Linking Polymer.

KSB S5: Preparation and Properties of a Cross-Linking Polymer

Solutions of the polymers polyvinyl alcohol (PVA) and polyvinyl acetate can be made into gels by addition of a borax solution. Borax cross-links the polymer chains. In this activity you will investigate interesting properties of gels. “Slime” is a polyvinyl alcohol polymer. “Gluep” is a polyvinyl acetate polymer.

You are to observe the effects of cross-linking polyvinyl alcohol and polyvinyl acetate chains with borax.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. The polyvinyl alcohol and borax solutions are nontoxic, but wash your hands when finished. Keep the gel in a plastic bag; keep off clothes and carpets.

Procedure

DJ – This icon will be displayed throughout the KSBs to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Part I. Making “Slime”

1. Obtain 50 mL of PVA solution in a disposable cup.
2. Use a wooden stirring stick—a glass stirring rod does not work as well—and stir the PVA solution. Note its viscosity. Is it more or less viscous than water?
3. If desired, add one drop food coloring to the PVA. Stir well.
4. Measure 12.5 mL of borax solution in a 25-mL graduated cylinder.
5. Pour the borax solution into the PVA. Stir vigorously until the gelling is complete.
6. Scrape the gel from the cup into your hands. Pat and knead it thoroughly to completely mix the components.
7. Divide your mixture into four equal amounts and place each section on its own piece of aluminum foil. For 15 minutes, refrigerate one, freeze the second, leave the third at room temperature, and save the fourth for Part IV. After 15 minutes, record the temperature of the three environments and bring all three samples to your lab table. Have each team member take a different sample and perform the following tests. **DJ**
8. When handling the samples, it is important that none of the material gets in your mouth. Your hands should be washed

Expected Student Background

Students should know:

1. How polymers are formed from monomers.
2. The functional organic alcohol group, -OH.
3. The concept of hydrogen bonding.
4. Acid-base reactions.
5. The concept of equilibrium.

Borax (sodium borate, $Na_2B_4O_7.10H_2O$) can be used to cross-link chains of polyvinyl alcohol polymer in water. The resulting network of cross-linked chains produces a gel that traps water molecules. This gel has fascinating properties when handled, squeezed, stirred, poured, or stretched. It can be used to demonstrate acid-base reactions and equilibrium.

Core Concepts and Skills

Standard 4 – The Physical Setting

- Types of organic reactions include: addition, substitution, polymerization, and esterification.
- Functional groups impart distinctive physical and chemical properties to organic compounds.
- Distinguish between nonpolar covalent bonds (two of the same nonmetals) and polar covalent bonds.

Time: 1 period

Safety Considerations

Read “Safety Considerations” in the student version. See also Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47.
The polyvinyl alcohol (PVA) solution, borax solution, and gel are not toxic. However, students should be cautioned not to make a mess with the gel. Do not let the students take the gel home.

Materials / Preparation (for 24 students working in pairs)

Making “Slime”
4% Polyvinyl alcohol, PVA, 240 mL (see Advance Preparation)
4% Borax, 100 mL (4.0 g household borax diluted to 100 mL)
12 Plastic or paper cups
12 Plastic teaspoons or 10-mL graduated cylinders
12 Popsicle sticks or tongue depressors
Food coloring
24 Zip-closure plastic bags
12 Graduated cylinders, 50-mL
12 Watch glasses or petri dishes

Making “Gluep”
Elmers (or any other white) glue, 200 mL
4% Borax, 100 mL (4.0 g household borax diluted to 100 mL)
Food coloring or tempera colors
12 Stir sticks (craft sticks or tongue depressors)
12 Plastic or paper cups, 6-oz. or 10-oz.
24 Zip-closure plastic bags
12 Teaspoon measures
12 Tablespoon measures

Effect of Acid and Base on PVA
2 M Hydrochloric acid, HCl, 100 mL (16 mL conc. HCl diluted to 100 mL)
2 M Sodium hydroxide, NaOH, 100 mL (8 g NaOH per 100 mL solution)

Advance Preparation
For “Slime”
PVA Solution: Use 99% hydrolyzed polyvinyl alcohol powder. (This can be ordered from most science supply companies.)
To prepare a 4% solution, weigh 40 g of 99% hydrolyzed polyvinyl alcohol. Gradually heat one liter of tap water. When it reaches 40–50 °C, gently sprinkle the powder into the water while constantly stirring (or use a magnetic stirrer). Keep heating gently and stirring until about 95 °C is reached; do not overheat or allow to boil. The solution will

look cloudy until it reaches 85–90 °C; then it will clear. Remove from heat; cover with aluminum foil, and allow to cool overnight. Store the mixture in a plastic bottle. It will keep for a long time.

An alternative method of producing "Slime"

[Recipe for slime using guar gum (a natural polymer)]

Guar gum, 0.5 g
4% sodium borate solution, 5 mL
[Fluorescein dye, 0.01 g, or food coloring (optional)]
Tap water, 100 mL
Clear plastic cup, 5-oz.
Wooden splint or Popsicle stick
Zip-closure plastic bag
Cylinder, graduated, 100-mL
Balance

Procedure:

1. Using the graduated cylinder, measure 100 mL of water and pour the water into a plastic cup.
2. Add a very small amount of fluorescein dye (0.01 g) to the water and stir with a wooden splint. (optional)
3. Weigh out 0.5 g of guar gum and add it to the cup. Stir until dissolved. The solution will thicken slightly in one to two minutes.
4. Using a graduated cylinder, measure out 5 mL of sodium borate solution. Add the solution to the cup and stir. The mixture should gel in one to two minutes. You will obtain your best results by making measurements as precisely as possible.

(The following steps are optional for fluorescent slime:)

5. Shine the black light on the dyed slime
6. The fluorescent slime may be stored in an airtight container (like a zip-closure plastic bag) to keep it from drying out.

For "Gluep"

50:50 Glue Solution: To make 50:50 glue solution, empty the bottle of glue into a container, letting it drain well. Then fill the glue bottle with water, shake, and empty into the container with the glue. (If you want to save time, make this ahead of time.) Prepare other solutions in advance as well. A mixture of liquid starch and glue also works, but you need to determine the appropriate amounts of each by trial and error.

Pre-Laboratory Discussion

Show students the dry PVA powder and the 4% borax solution. Demonstrate the solution's viscosity by pouring it from one beaker to another. Explain how PVA and borax solutions were made. Show the structural formula of polymer chains and borate ion. In water, the borax hydrolyzes to form a borate-boric acid buffer system: $B(OH)_3$ + 2 H_2O $B(OH)_4^-$ + H_3O^+

The $B(OH)_4^-$ ion is believed to cross-link the polymer chains as shown in Figure 2.

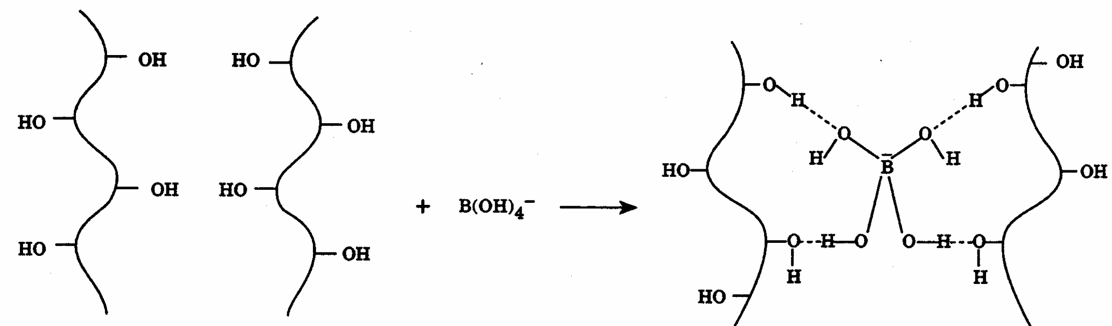


Figure 2. Structure of "slime"

Demonstration: "People Polymers"

1. Arrange four students in a line holding hands; put four other students in a second line behind the first line. These formations represent the PVA chains. Can they move freely?
2. Ask two other students to walk between the lines, and take hold of a student on each side. These students represent the borate ions. Can the PVA chains move freely now? If there were water molecules between the chains, what would happen to them? (They would be trapped in a three-dimensional network, which we call a gel.)

Teacher-Student Interaction

Part I

1. Why is PVA solution so viscous? [*Because long polymer chains cannot move freely.*]
2. Try to imagine the many long chains of molecules, being pushed around as you stir it. Describe your mental model. [*It is sort of like a bucket full of eels*.]
3. After the cross-linking, why does the gel have to be kneaded thoroughly? [*To provide complete mixing.*]
4. How is the gel like a liquid? [*It flows, has no definite structure, takes any shape.*] How is it like a solid? [*It can be broken with a sharp pull; it bounces.*]
5. Be sure students understand what was seen: PVA chains cross-link with the $B(OH)_4^-$ ion, forming a gel that traps water molecules.

Part II

1. Why does acid destroy the properties of the gel? [*Hydronium ions break hydrogen bonds between chains*.]
2. How have the properties changed after addition of NaOH? [*It again becomes a gel—it stretches, bounces, drips*.]
3. Why does base restore the gel's properties? [*It neutralizes hydronium ions, permitting cross-linking to reoccur.]*

Anticipated Student Results
Students produce a gel (it's colorful, if food coloring has been added) that has interesting properties: It can be dripped, stretched, patted, rolled into a ball, bounced on a *clean* surface, etc. Students should be expected to observe these properties and record them. Students will notice how rapidly the cross-linking takes place. Encourage them to ask the question, "If the borax solution is diluted to 1% or 2%, will the gelling occur as fast?" Then try it!

Acid-Base Activity
When one drop of 2 M HCl solution is placed on a dime-sized piece of gel, the gel starts to dissolve in a few seconds. Adding one or two drops of 2 M NaOH solution restores the original properties of the gel.

Responses to Part I. Implications and Applications
1. Cross-linking occurs by hydrogen bonding, not covalent bonding.
2. Because -OH groups of the borate ion can hydrogen bond with -OH groups of PVA polymer chains (see Figure 3). Hydrogen bonding is so weak that this could account for the ease of stretching and dripping, and the other observed properties.

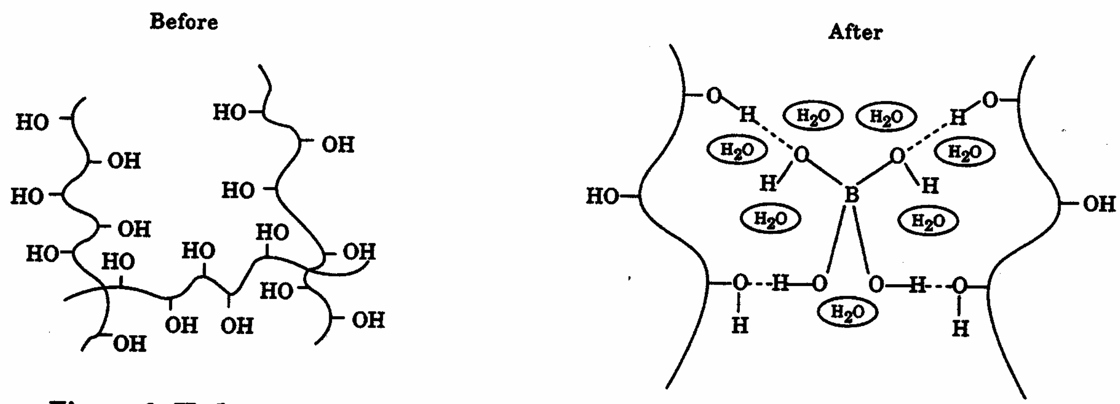


Figure 3. Hydrogen bonding in slime.

Responses to Part II. Data Analysis and Concept Development

1. (Observation)
2. One more drop than drops of HCl.
3. $NaOH + HCl \longrightarrow NaCl + HOH$.

Post-Laboratory Discussion

1. Ask students to list the properties of PVA solution before and after gelling. [*Before gelling: syrupy, liquid. After gelling: if pulled suddenly will break, malleable, semisolid.*]
2. How does hydrogen bonding explain the gel's properties (i.e., how it can be squeezed, dripped, stretched, etc.)? [*Hydrogen bonds can be more easily broken and reformed; covalent bonds are too strong to cause these properties.*]
3. How do you explain the effect of HCl and NaOH, in terms of equilibrium?

$$[\textit{gel} \underset{NaOH}{\overset{HCl}{\rightleftharpoons}} \textit{liquid}]$$

4. Can you think of uses for the gel other than for a toy? [*Special effects in motion pictures—e.g., people's faces melting in* Raiders of the Lost Ark.]

Extensions

1. Allow some gel to dry in air, and observe its properties. [*Becomes brittle and curls around the edge.*] Can it be rehydrated? [*No.*]
2. Let students color some clear gel with fluorescent highlighter pens. Then observe under ultraviolet light. (CAUTION: Protect eyes from ultraviolet light!) [*Glows brilliantly!*]
3. Try using 2% PVA solution and 2% borax solution (or other proportions). [*No satisfactory gel is formed.*]
4. Will other acids and bases have the same effect as HCl and NaOH? [*Yes.*]

Assessing Laboratory Learning

1. Draw "pictures in the mind" of the polymer before and after gelling. Include some water molecules in your picture.
2. Describe the viscosity of the PVA solution before and after gelling. [*It's higher after gelling.*] Can it still be poured? [*Yes. It will run through the funnel.*]
3. In this activity, why is it not critical to use "exactly" 20 mL of PVA solution and "exactly" 4 mL of the borax solution? Why is it important in other activities to be *very* exact in your measurements? [*The extent of cross-linking depends on the amount of borax. The properties of "slime" depend on varying the number of cross-links.*]

References

Casassa, E.Z., Sarquis, A.M., and Van Dyke, C.H. (1986). The gelation of polyvinyl alcohol with borax. *Journal of Chemical Education, 63,* 57.
Sarquis, A.M. (1986). Dramatization of polymeric bonding using slime. *Journal of Chemical Education, 63,* 60.
*CHEM FA*X. Polyvinyl alcohol, preparation of a 4% solution for the "slime" activity. Flinn Scientific. (131 Flinn Street, Batavia, IL 60510. Call (708) 879-6900 to put your name on their mailing list.)

- Copy and distribute KSB S6: Which Polymers “Hold” Water?

KSB S6: Which Polymers “Hold” Water?

Plastic grocery bags maintain their strength even when wet. Paper bags, on the other hand, lose much of their strength when wet. Intermolecular force accounts for the differences in the way plastic and paper interact with water.

DJ – This icon will be displayed throughout the KSBs to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Cellulose paper contains a polymer of glucose. Glucose is very soluble in water. Devise a method that would allow you to determine how much glucose will dissolve in water. Write out explicit steps in your Design Journal so that a classmate could follow your instructions. What units would your answer have? **DJ**

Develop your understanding:

Part I: “Getting wet”

1. a. We know that glucose is soluble in water. Do you think cellulose, a polymer of glucose, would be soluble in water? Support your prediction. **DJ**

   b. Test your prediction by placing cellulose in water. Describe your results. **DJ**

2. Cellulose is produced by the action of enzymes as plant cells grow. Enzymes are examples of natural catalysts. An enzyme called *cellulase* can break down cellulose. If cellulase were added to your cellulose-water mixture, would you expect to see any changes? If so, what would you see? Provide support for your response. **DJ**

3. Using a sample of iodine in water:

   a. What is the color of the iodine-water mixture? **DJ**

Expected Student Background

The students should be able to explain the molecular differences between polar and nonpolar molecules. They should know that water has polar molecules.

Core Concepts and Skills

Standard 1 – Conduct controlled experiments and design and/or carry out experiments, using scientific methodology.
Standard 4 – Apply the adage “like dissolves like” to real-world situations.
Standards 3–5 – Identify and investigate factors relevant to design performance.

Time: 1 period

Safety Considerations

Remind students to follow all standard safety procedures while working on this activity. See also Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47. Students should use extreme caution when working with the iodine solution to avoid contact with skin, eyes, and clothing. Provide proper ventilation when the students spray the Scotchgard™ on the paper bag material and instruct them to direct the spray away from themselves and others.

Materials / Preparation

Glucose
Cellulose powder or sawdust or shredded paper
Iodine-water solution
Oil (mineral oil, lamp oil)
Scotchgard™
Brown paper bags

Plastic bags or wrap
Scissors
Masking tape

You may want to discuss the solubility/miscibility of liquids prior to the activity or use this activity to allow students to discover this concept.
During the activity, be sure to point out the relationship of molecular polarity and solubility.
You may want to have molecular modeling kits to allow students to investigate the polarity of molecules.

Additional topics that might be added:

1. Discuss the process of "wicking" of water as it relates to winter clothing.
2. Discuss factors that affect windchill as it relates to winter clothing.

Responses to Questions

Which polymers "hold" water?

1. a. No, paper bags don't dissolve in water.
   b. The white cellulose powder does not dissolve in water.
2. As the cellulose is broken down into shorter and shorter chains, it becomes more and more soluble.
3. a. Reddish-brown
   b. The oil turns pink/purple. The iodine is more soluble in oil than it is in water.

Why do some polymers "hold" water while others do not?

1. See attached sheet of molecule structures a. – i.
2. Those that are polar will dissolve ("like dissolves like").
3. All nonpolar monomers from 1.

Applying Your Ideas

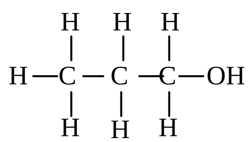
1. "Scotchgarded" paper will shed water. Scotchgard™ is nonpolar so it is not attracted to water.
2. Cellulose has many polar -OH groups. Many things that would stain fabrics are polar. Although these stains are attracted to the cellulose, the layer of Scotchgard™ prevents the stains from penetrating to the fabric.

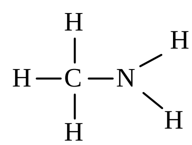
Perspiration Inspiration

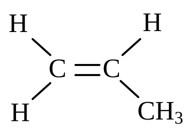
1. The evaporation of moisture causes cooling of the skin.
2. About 1 liter is lost through perspiration.
3. Both salts and molecular substances are lost in addition to the water.

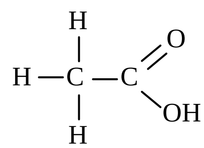
Below are the structures for the monomer molecules in KSB S6: Part II: Why do some polymers “hold” water while others do not?

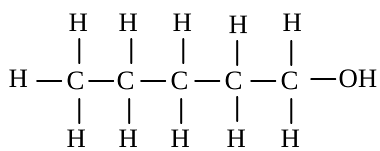
These are simple structural formulas for the monomers. The students may sketch the molecules differently but hopefully their structures will be structurally correct.

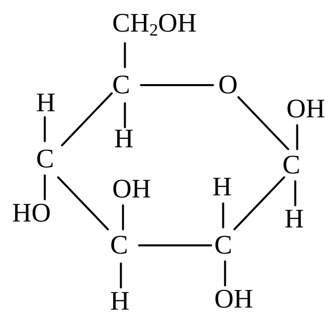
a. 

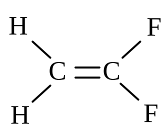
b. 

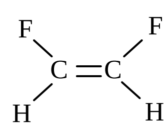
c. 

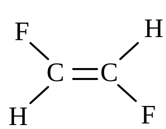
d. 

e. 

f. 

g. 

h. 

i. 

- Copy and distribute KSB T3: Impact Effects: “Dropped Dart Tests.”

Expected Student Background

This activity involves testing the individual layers of polymer material that students consider for their composite. They will need to have some experience in experimental design and measurement of mass and distance.

Core Concepts and Skills

Standards 3–5
Guides students as they identify and investigate factors relevant to design performance and facilitates acquisition of mathematical, scientific, and technological principles related to polymers.

Time: 1 period

Safety Considerations

Standard safety procedures should be followed during this activity. See also Additional Support for Teachers, “Recommendations for Safe Laboratory Practices,” page 47. Students should be warned about dropping the weights since some may bounce and fall from the lab desk.

KSB T3: Impact Effects: “Dropped Dart Tests”

Sheets or films can be tested for impact resistance in a variety of ways. One method is called a “dart” test. This involves mounting the sheet or film securely on the top of a large metal can and dropping a dense weight on the sheet or film to determine the breaking point.

Safety: Follow all standard safety procedures during this activity.

Materials

Large can (height and diameter at least 10 cm; e.g., a coffee can)
Wide rubber bands
Meterstick or tape measure
Various plastic film and sheet samples (e.g., trash bags, food wrap, sections of bleach bottle, plastic food container material, grocery bags, dry cleaning bags)
“Darts”: various sizes of weighted balls, smooth weights, or bolts with smooth and rounded tops

DJ – This icon will be displayed throughout the KSBs to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Part I

Develop a dart test where the weight of the dart *changes* while the height remains *fixed*. Determine the impact needed to break a variety of plastic film and/or sheet samples. **DJ**

Part II

Develop a dart test where the height of the fall *changes* while the weight of the dart remains *fixed*. Determine the impact needed to break a variety of plastic film and/or

Materials / Preparation

Large coffee can or other cans of suitable size
Wide rubber bands
Meterstick or tape measure
Various plastic film samples (e.g., trash bags, food wrap, sections of bleach bottle, plastic food container material, grocery bags, dry cleaning bags)
Darts: different-weight metal spheres, smooth weights, or different-weight large hex nuts

Tests that are suggested to determine a material's impact strength include one that varies the height of drop and one that varies the weight dropped. The students are to select one method and then design the specifics of the test.

To determine the impact, multiply the mass of the dart by the height of the fall. NOTE: The coffee can has a plastic film sample secured over the opening with a strong elastic band.

Impact calculation: mass x distance = impact

First procedure design option

Ask students to develop a dart test in which the weight of the dart changes while the height remains fixed. Ask them to determine the impact force needed to break a variety of plastic film samples.

Second procedure design option

Ask students to develop a dart test in which the height of the fall changes while the weight of the dart remains fixed. Ask them to determine the impact force needed to break a variety of plastic film samples.

Additional testing

In this series of tests the students will test the durability of one of the sheets or films tested in the impact test above. They should set up a test like the one they did above in which the material does not break with the first impact. They then repeat the same drop a number of times (max. = 10) to see if there is material fatigue causing failure after repeated drops. Switching to a heavier weight or higher height would give them information about durability with higher impacts. They may find that some materials fatigue and fail after repeated drops. By sharing information with other groups, they may find that some materials are more resistant to fatigue.

Responses to Questions

Students should have recorded their procedure, all pertinent data, and conclusions about the investigation that they designed to assist them in the design and production of their composite.

- Copy and distribute KSB T4: Glue: Holding It All Together.

Expected Student Background

Students need to be able to follow directions carefully, and keep well-organized data and observations.

Core Concepts and Skills

Standards 3–5
Guides students as they identify and investigate factors relevant to design performance and facilitates acquisition of mathematical, scientific, and technological principles related to polymers.

Time: 2 periods

Safety Considerations

Remind students to follow standard safety procedures while working on this activity. See also Additional Support for Teachers, "Recommendations for Safe Laboratory Practices," page 47. Students should be warned to avoid the vapors from the adhesives, and keep the adhesives from contact with skin, eyes, and clothes.

> **KSB T4: Glue: Holding It All Together**
>
> "Glue" may be many different substances. It is typically used to bond one material to another or to join two pieces of the same material. Even water can act as glue for a short time, holding two pieces of paper together. This is due to the intermolecular forces between water and the cellulose fibers in the paper. Glues work because of the bond-like forces that can occur between two materials.
> Durable adhesives are more desirable for bonding two surfaces together. Strong glues contain molecules with strong intermolecular attractions for each other and for the material to be connected. This can be as simple as gluing cutouts on a collage or as critical as gluing parts for a huge passenger airplane.
>
> **Safety**
> - Follow all standard safety procedures while working on this activity.
> - Keep the glues away from flame, heat, or sparks.
> - Use caution when using scissors or other cutting tools.
>
> **DJ** – This icon will be displayed throughout the KSBs to indicate when you should record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.
>
> **PART I: Evaluating Glues**
>
> Your instructor will assign each member of your group four (4) glues to test.
> - Using a sheet of aluminum foil about 60 cm long, place two penny-sized samples of your glue (about 1.5 cm in diameter) on the foil.
> - Space the two samples about 3 cm apart and spread the second sample with a flat wooden stick, e.g., a tongue depressor, to form a thin layer.
> - Record the time when you place each sample on the

Materials / Preparation

Aluminum foil (regular or heavy-duty)
An assortment of types of glue and adhesives

List of suggested glues

White school glue or carpenter's glue
Epoxy glue and/or putty
Silicone glue
Mucilage
Contact cement
Glue for vinyl (as for pool liners)
Hot melt glue
Auto body putty
Flat wooden stick (tongue depressors, Popsicle sticks, etc.)
Clock
Metric ruler
Medium-sized test tubes with stopper to fit
Samples of polymer materials that may be used for the composite. This can be any variety of sheets, films, and fabrics from local sources. The students may bring in materials but should get permission before use. Try to have a mixture of natural and synthetic materials:

    Polyethylene, PVC, polystyrene, nylon, Lucite, etc.
    Paper, cotton, wood, straw, etc.

Scissors and other cutting tools: carton cutter, metal shears, paper cutter, handsaw, etc.

[Ask students if they have experience with the other cutting tools before they use them. If necessary, instruct them in the safe use of the tools. You may need to be instructed, also. If so, ask a technology teacher.]

[You may also need to provide appropriate "weight" (e.g., rocks, old books, etc.) to place on the glued material samples.]
Hole punch
Spring scales (at least two different force ranges)
Butterfly-type paper clips (note that these will become deformed with use but may be reused anyway)

Once the groups have read the overview, give them time to discuss their plans for evaluating glues.
Assign each group four (4) different glues to test. Note that there will be some repeating of the assigned glues among groups. This will allow for comparisons of results on similar tests. Try to assign the glues in a variety of combinations even though one or two glues may duplicate those of another group member.
Monitor the work and use questioning techniques with students and groups to encourage self-evaluation of methods and processes. Strive to avoid giving answers.
Check that results have been recorded and shared within and among groups.
Encourage meaningful discussion of the glues and adhesives that may be used for the group's composite. Notes from this discussion should be recorded in the Design Journals.

Be aware that some of the glues and adhesives may have an adverse effect on the polymers. The solvents in some glues will degrade polymers such as polystyrene. Provide space for the students to store their samples overnight as some glues will take that long to dry. Have students make note of degradation and suggest they research the causes. Supervise the strength tests and, as needed, assist the students in making the measurements. You may choose to demonstrate these tests with some premade samples. Practice using the spring scale if it is not familiar to you.
Provide time for the groups to share the results and make comparisons. Students should be ready to defend the results of their tests if results for the same combinations are different.

Responses to Questions

Students should have recorded their procedure, all pertinent data, and conclusions about the investigation that they designed to assist them in the design and production of their composite.

Coordinating student progress (continued)

Planning and constructing: Continue to work as a facilitator as groups select their preferred alternative and develop plans for construction. Facilitate a discussion of trade-offs that are made in the search for an optimal design solution. Encourage groups to identify and model functional design elements and construct their working prototype.

Testing: Bring students together as a large group and discuss ways in which each group might test their design. Facilitate small group development of testing and evaluation procedures.

Redesign: Bring all groups together to compare results. Encourage student groups to carefully review the work of other groups to glean ideas that might inform a redesign. When redesign is discussed, continue to direct students' attention to how the understanding and application of MST concepts can guide improvements.

Uniting the class in thinking about what has been accomplished

Bring the whole class together after they have completed the manufacturing and testing of the composite to share their successes and setbacks. Students will benefit from having their work critiqued by their peers. They will also be able to critique their own work by comparing the strengths and weaknesses of their process and product with those of other teams. If time permits, allow time for a design team presentation, as well as an individual, written Design Report.

Design Report: The reports provide one of the major opportunities for you to determine whether individuals have attained the goals for this module. Continue to work as a facilitator as groups document their progress and share results within the group. Explain that each student must submit a Design Report. Assist individuals in structuring and writing their Design Reports. The Design Report should include justifications for the redesign decisions and cite test results. Remind students that the report should include data to convince the management of the recreational company to use this composite for the product line as described in the Introductory Packet. Provide students with the Design Report guidelines from the NYSCATE *Pedagogical Framework*. When you introduced this module, you told students that careful documentation in the Design Journal leads to a well-written final report later on. For individuals who have trouble writing, check their documentation frequently along the way to ensure that they will have a source of information adequate to generate a report.

Group presentations: Discuss with the class what is considered proper and expected deportment during group presentations. Address the need to use a variety of media to support the presentation. Review and distribute the presentation guidelines from the NYSCATE *Pedagogical Framework*.

During the group presentations to the class, encourage the other students (through example) to ask appropriate questions and provide constructive feedback to the presenters.

Each group should have a spokesperson to briefly share the information with the whole class. The presentation may be oral or in the form of a poster display. If these efforts will be graded, students should be informed ahead of time of the criteria to be used.

The ideal situation is for each team to have an opportunity to present a full report to the entire class. However, if sufficient time is not available, students can make mini-presentations. Each of these mini-presentations should be about 30 seconds to 1 minute in length. The spokesperson should begin with a very brief description of the composite and its intended use. Encourage students to ask appropriate questions and provide constructive feedback to the presenters. Your own questions and feedback will serve as a model for appropriate student behavior during the presentations.

Assessing student design work: Assessing the design process as well as the finished design solution is an important consideration in evaluating design-related activities of students. Each component of these activities is represented in rubrics that are generic to all NYSCATE design activities. The entire set of rubrics is included in this module on pages 52–56. You can apply these rubrics to students' Design Journals, Design Reports, and group presentations to the class. It is also appropriate to supplement the rubrics with multiple choice, short answer, or extended response questions that assess design understandings, content knowledge, and technical skills. For further explanation of the use of the rubrics and the NYSCATE philosophy of assessment, see the relevant section in the NYSCATE *Pedagogical Framework* (p. 28).

Summing up progress on the learning goals

Individual students. Your final FOCUS must be on summing up individual progress toward meeting the learning goals as well as the effectiveness of instruction. Keeping in mind that the Design Challenge is a means of accomplishing the learning goals, review the module's learning goals periodically to stay on track during the module and during its assessment. The NYSCATE *Pedagogical Framework* suggests tools for this assessment, including process-rating forms, content tests, and the preliminary product-scoring rubrics described above. The assessment methods you select should be consistent with the methods of grading you presented to students during the organizing phase of this module.

Module effectiveness. The Design Reports and presentations described above are valuable sources for evaluating module effectiveness as well as individual progress. In addition, you will find it helpful to keep notes on the module and on student involvement throughout the module. You can then evaluate module effectiveness to guide improvements in the module and in instruction for the next time you use the module. You may gain valuable insights into how to improve instruction the next time by initiating an informal discussion with students.

VII. ADDITIONAL SUPPORT FOR TEACHERS

OVERVIEW OF *POLYMERS* (Adapted from Sourcebook:ChemSource, Inc. 1997)

History may be described in terms of the materials employed in making useful items—the Stone Age, the Bronze Age, and the Iron Age. The 20th century is appropriately known as the Polymer Age, since most items we use daily are made from polymers.

Natural polymers such as DNA, RNA, proteins, cellulose, and starch have existed since the beginning of life on Earth. Over 2,000 years ago, the Chinese developed the process of papermaking and Central American natives learned how to make rubber balls from the juice of certain trees. In the 1800s scientists and inventors began to convert natural polymers into products displaying useful properties. Charles Goodyear learned how to vulcanize rubber; Christian Schonbein changed cellulose into nitrocellulose; John Hyatt made celluloid from nitrocellulose and camphor; Louis Chardonnet produced artificial silk from nitrocellulose.

Large-scale production of purely synthetic polymers began in 1909 when Leo Baekeland developed the phenolic resin he called “Bakelite.” The polymer industry grew exponentially, and today it is difficult to list all of the various polymers available. In the 1920s, the term *plastics* was used to describe these new materials. It is estimated that 75% of all chemists working today are in some field of polymer science.

Simply described, polymers are giant molecules made up of long chains of repeating units. *Poly* means *many* and *mer* means *part*. All polymers are made from small units called **monomers,** joined in long chains by covalent bonds. For example, polyethylene is made from many ethylene molecules, and polystyrene is made from styrene molecules.

The process of polymerization can proceed in two general ways: addition and condensation, depending upon the types of monomers used. In **addition polymers** (chain-growth polymers), one monomer simply adds to the next, which adds to another, and another, etc*.* Chains of polyethylene can have 10,000–20,000 ethylene units. In **condensation polymers** (step-growth polymers), two different monomers are joined together with the elimination of a small molecule, such as water. Nylon and polyester are examples of condensation polymers.

If the polymer chains are cross-linked, the product will usually be much more rigid and resistant to heat. **Thermoplastic polymers** can be heated and remolded many times; **thermoset polymers** cannot be remolded once they have been originally shaped because they are cross-linked. Heat does not soften thermosets; they simply char if exposed to flame. Polyethylene and nylon are thermoplastics; Formica™. countertops and epoxy putty are thermosets. Toothbrush handles are made of a thermoplastic polymer, while handles of kitchen utensils are fabricated from thermoset polymers.

Recommendations for Safe Laboratory Practices

1. Never perform any lab work unless the instructor is present.
2. Know the safety rules and procedures that apply to each lab exercise. Be sure to ask your instructor if you do not understand anything explained to you about the procedure.
3. Know the location and use of emergency equipment (fire extinguisher, eyewash station, fire blanket) and emergency exits.
4. Check all lab equipment before using.
5. Consuming food or beverages in the lab is prohibited.
6. Correctly and clearly label all chemical containers used in a lab activity.
7. Avoid distracting or startling anyone in the lab. Misbehavior will not be tolerated.
8. Report any spill, injury, or unsafe condition to the instructor immediately.
9. Use equipment and chemicals ONLY for their designated purposes.
10. Use caution when using any cutting utensils.
11. Always wear appropriate eye protection during lab exercises.
12. Wear lab aprons during lab exercises.
13. Do not remove your shoes.
14. Work areas should be kept clean and free from obstructions.
15. Exercise caution when picking up broken glass and dispose of all broken glass in the glass disposal container.
16. Before lighting a flame, remove all flammable material from the work area. Tie back hair and tuck in any loose clothing.
17. Only use spark strikers for lighting burners.
18. If the burner goes out or is malfunctioning, immediately shut it off; seek assistance.
19. Clean your lab area when you have completed your work.
20. Wash your hands thoroughly after you have completed lab work.
21. Follow the lab procedure as either explained on handout or approved by your instructor. Never try an experiment on your own.
22. Avoid personal contact (through smelling, tasting, touching) with hazardous chemicals.
23. If a hazardous chemical gets on your person or clothing, rinse with water immediately and tell your instructor.

I have read the above recommendations and understand what is meant by each of them. I have had an opportunity to ask questions.

I understand that unsafe activity can result in removal from this course.

____________________ __________________________ _______
(Student signature) (Name of school) date

__________________________ _______
(Parent signature) date

BUILDING KNOWLEDGE AND SKILL

The challenge your students face involves designing a composite for use with a snowmobile. Many will want to proceed by trial and error alone. To prevent this, you must convince them that they need to find out what they now know as a group and what they will need to know about the process of design, and about polymers and their properties, in order to complete the challenge properly. The Knowledge and Skill Builders (KSBs) are meant to help students become more informed in both of these areas just in time. Refer to the NYSCATE *Pedagogical Framework* for additional information on the informed design process.

LEARNING STANDARDS THAT RELATE TO *POLYMERS*

Polymers places major emphasis on the following learning standards:

Learning Standards for Mathematics, Science, and Technology (The University of the State of New York, The State Education Department)

Standard 1 – Analysis, Inquiry, and Design
Observations made while testing provide new insights into phenomena.

- Represent and organize observations and interpret data.
- Develop a written report that describes proposed explanations.

Engineering design is an iterative process involving modeling and optimization, and is used to develop technological solutions to problems within given constraints.

- Carry out a thorough investigation and identify needs for technological innovation.
- Use a wide range of information resources and document findings.
- Generate a variety of solutions and choose the optimal solution on the basis of specifications and constraints.
- Develop working plans.
- Devise and perform a test of the solution.

Standard 3 – Mathematics
Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships.

- Model real-world problems with equations.

Standard 4 – Science
Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

Standard 5 – Technology

Technological tools, materials, and other resources should be selected on the basis of safety, cost, availability, appropriateness, and environmental impact; technological processes change energy, information, and material resources into more useful forms.

- Select appropriate tools, instruments, and equipment and use them correctly to process materials, energy, and information.
- Explain trade-offs made in selecting alternatives.

Standard 6 – Interconnectedness: Common Themes

Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

- Collect information about the behavior of a system and use modeling tools to represent the operation of the system.

Standard 7 – Interdisciplinary Problem Solving

- The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.
- Design solutions to real-world problems, using a technological design process that integrates scientific investigation and rigorous mathematical analysis of the problem and the solution.
- Explain and evaluate phenomena mathematically and scientifically.

Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results.

- Students participate in an extended mathematics, science, and technology project in which they work effectively; gather and process information; generate, analyze, and implement ideas; and present results.

Learning Standards for Career Development and Occupational Studies (The University of the State of New York, The State Education Department)

Standard 2 – Integrated Learning

Integrated learning encourages students to use essential academic concepts, facts, and procedures in applications related to life skills and the world of work. This approach allows students to see the usefulness of the concepts they are being asked to learn and to understand their potential application in the world of work.

•Demonstrate the integration and application of academic and occupational skills in their school learning, work, and personal lives.

•Use academic knowledge and skills in an occupational context, and demonstrate the application of these skills by using a variety of

•communication techniques (e.g., sign language, pictures, videos, reports, and technology).
•Research, interpret, analyze, and evaluate information and experiences as related to academic knowledge.

Standard 3A – Universal Foundation Skills
Basic skills include the ability to read, write, listen, and speak as well as perform arithmetical and mathematical functions.
•Use a combination of techniques to read or listen to complex information and analyze what they hear or read.
•Convey information confidently and coherently in written or oral form.
•Analyze and solve mathematical problems requiring use of multiple computational skills.

Thinking skills lead to problem solving, experimenting, and focused observation and allow the application of knowledge to new and unfamiliar situations.
•Demonstrate the ability to organize and process information and apply skills in new ways.

National Standards for Technological Literacy

Standard 2
Students will develop an understanding of the core concepts of technology.
•Z: Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste.
•AA: Requirements involve the identification of the criteria and constraints of a product or system and the determination of how they affect the final design and development.

Sample Design Challenge Letter

(on following page)

To Chemistry Research and Development Scientists:

Here at ***Snowy Recreations,*** we are developing a new line of snowmobile equipment for the 2003–2004 season. We request that you work in a group to design a new line of polymer composites for use in our snowmobile products. Your group should design and test a composite of multiple layers of polymer bonded together to form a material that can be used for one of these purposes:

1. The shell of the snowmobile
2. A snowmobile suit
3. Protective cover for the snowmobile

Your composite must be at least five layers and incorporate at least one synthetic and one natural polymer. Your group should have one sample of your polymer composite to submit along with the individual Composite Design Reports. The reports must include all of the tests performed to support the use of your polymer composite as suitable for its intended purpose.

We also ask for a well-written Design Journal from each individual. We may use the journals to help mass-produce your design. Each individual in your group should complete a final report, at least two pages in length, typed and double-spaced. The report should also contain all data tables, notes, and specific observations. Also include a labeled diagram showing an exploded view of the structure of your polymer composite.

We will be in contact with you to arrange for your group's presentation. The presentation should include a variety of media to display your findings. You will be assessed on the design development tasks (Knowledge and Skill Builders), the Design Journal, the Design Report on your composite, and your group's presentation.

Thank you for your cooperation.

CB Snowy

Snowy Recreations, Inc

Assessment Strategies for *POLYMERS*

The assessment of student design work considers many factors and focuses on the design process as well as the finished product (design solution). Each component of design-related student activity is represented in rubrics that are generic to all NYSCATE design activities. However, you can tailor the generic rubrics to a particular assignment, and you should discuss them in advance to make students aware of the evaluation process. You can assess student design processes and products by reviewing students' Design Journals, Design Reports, and group presentations to the class. Multiple choice, short answer, or extended response questions that assess design understandings, content knowledge, and technical skills are also appropriate.

Assessment of students’ Design Reports and Design Journals involves consideration of multiple factors; you must focus on the process as well as the product.

The scoring scale that follows is consistent with a scale developed by the National Council of Teachers of English:

4—exceeding the level that you target in teaching
3—meeting the level that you target in teaching
2—developing to the level that you target in teaching
1—emerging

The following set of preliminary design assessment rubrics is general. You can tailor them to particular assignments. As the NYSCATE project conducts field-testing, pools of student work will be collected for various modules, and benchmark papers will be identified to exemplify the differences among scoring categories. If you use these preliminary rubrics, you should present them to and discuss them with your students ahead of time so they become aware of and a part of the process through which they are being evaluated.

- ***The Design Process***

A. Explained problem and identified constraints and specifications.

4. Explained the problem in detail and from this context illustrated the necessary constraints and specifications.
3. Explained the problem in a few sentences, and provided two constraints and two specifications.
2. Briefly explained the problem, and provided one constraint and one specification.
1. Did not explain the problem, and provided no or only one constraint and specification.

B. **Researched the problem and developed information from Knowledge and Skill Builders.**
4. Knowledge and Skill Builder completely and accurately performed with further investigations developed as a result of the investigations.
3. Knowledge and Skill Builder was completely and accurately performed.
2. Knowledge and Skill Builder was incompletely performed, but attempts were made in all three areas.
1. Knowledge and Skill Builder was poorly performed. Not all areas were attempted.

C. **Justified optimum design.**
4. Provided three to four alternative solutions. Used sketches to represent solutions. Undertook math, science, and technological investigations that were used to justify optimum design.
3. Provided two to three alternative solutions. Used sketches to represent solutions. Undertook science and technological investigations that were used to justify optimum design.
2. Provided one to two alternative solutions. Used sketches to marginally represent solutions. Undertook minor investigations that were used to justify optimum design.
1. Provided one solution. Used sketch to marginally represent solution. Few or no math, science, and technological investigations were used to justify optimum design.

- ***The Design Solution***

A. **An accurate sketch of your final, as built, design was drawn.**
4. Drawing was on graph paper to scale with all elements included. Multiple views (top, side, and front) were shown.
3. Drawing was on graph paper to scale with all elements included. Drawing showed the design in two dimensions—a flat view.
2. Drawing was on graph paper reasonably to scale with most elements included.
1. Drawing was not to scale and important elements were missing.

B. **Materials and tools were planned and used appropriately in constructing project.**
4. Prepared a list of materials and tools present and included an explanation of how they would be used appropriately in the construction.
3. Prepared complete list of materials required and tools necessary to fabricate with these materials.
2. List of materials was essentially complete; some tools required were not mentioned.
1. Mentioned only a few materials and tools.

C. The solution worked. It met the design specifications and constraints.

4. The solution solved the problem statement; this was explained in the write-up along with how the specifications and constraints were addressed and/or how the design was modified to assure their being met.
3. The solution solved the problem statement and the constraints and specifications were met.
2. The solution solved the problem but not all constraints and specifications were met in doing so.
1. The solution did not solve the problem; constraints and specifications were not met.

D. The design was creative.

4. The solution was unique; never or seldom has this design been formulated.
3. The solution was functional, but not unique. Similar solutions were common.
2. The solution was similar to others; it may have been a modification or interpretation of someone else's solution.
1. The solution appears to be copied from someone else's work.

- ***Mathematical, Scientific, and Technological Connections***

A. Presented results in graphs and charts.

4. Graphs and charts were neatly drawn with graphic illustration. Graphing software, if appropriate, was used.
3. Graphs and charts were drawn neatly on graph paper. Labels were appropriate.
2. There were some graphs and charts drawn with moderate care.
1. Charts and graphs were poorly done. Information was missing.

B. Used accurate analysis and calculation.

4. Used appropriate mathematical and scientific analysis to inform the design. Conducted the analysis in a logical fashion, clearly showing methodology used and justifying procedure.
3. Used appropriate mathematical and scientific analysis to inform the design. Conducted the analysis in a logical fashion, clearly showing methodology.
2. Used appropriate mathematical and scientific analysis to inform the design. Some minor errors were made.
1. Significant errors were made in analysis and procedures.

C. Tested the design.

4. Conducted the test in a reliable and scientific fashion with multiple tests run to demonstrate repeatability. Discussed why the testing was reliable and described efforts made to assure it would be.

3. Conducted the tests in a reliable and scientific fashion with multiple tests to demonstrate repeatability.
2. Conducted the test once. Did not show reliability or repeatability of data.
1. Did not perform testing of design.

D. Provided conclusions based on the testing and made recommendations for improvements for redesign.

4. Analyzed the results from testing and made sense of them. Based on this analysis, made recommendations for design improvements and then modified the design and retested to show the benefit of the modifications.
3. Analyzed the results from testing and made sense of them. Based on this analysis, made recommendations for design improvements.
2. Analyzed the results and suggested design improvements but justification was missing.
1. Did not reach conclusions from testing or recommend design modifications based on the testing.

- ***Work Habits***

A. Worked collaboratively with classmates.

4. Worked cooperatively with others both as a leader and as a follower. Helped focus the group on the task at hand and assisted others.
3. Worked cooperatively with others, assisting occasionally.
2. Worked alone, completing assignments.
1. Worked alone. Did not complete assignments.

B. Completed assigned tasks in a timely fashion.

4. Maintained a journal/daily log of project. Completed personal assignments on time, and assisted others in keeping group on time.
3. Maintained a journal/daily log of project; personal assignments were completed on time.
2. Most personal assignments were completed on time; journal/daily log was erratically maintained.
1. Assignments were turned in late or were incomplete; journal/daily log was not maintained.

- ***Communication and Presentation***

A. Design portfolio was complete and neat in appearance.

4. All sections of portfolio were completed; portfolio was typed, and sentences were complete and grammatically correct. There were no spelling errors.
3. All sections of portfolio were completed; handwriting was neat and sentences were complete, grammatically correct, and free of spelling errors.
2. All sections were attempted, and most sections of the portfolio were completed. Phrases and sentences were used; there were some grammatical/spelling errors, and handwriting was legible.
1. Not all sections were attempted; work was incomplete. There were grammatical/spelling errors, and handwriting was illegible.

B. Actively participated in the presentation of results.

4. Knowledgeable of own material and clearly presented same. Language skills were good. Interacted with others, and acted as group leader with support of group.
3. Knowledgeable of own material and clearly presented same. Language skills were good. Interacted with others.
2. Knowledgeable of own material and presented same.
1. Did not actively participate. Information misunderstood.

VIII. STUDENT HANDOUT SECTION

Student Handout section begins on the next page.

DESIGN CHALLENGE OVERVIEW HANDOUT

Your group is part of the research and development unit for a large recreational equipment and supply company. Your group has been assigned the task of designing and testing a new polymer composite for use in one of the company's new products, a fully outfitted snowmobile.

Design Challenge
Design and test a composite of multiple layers of polymer material bonded together to form a material suitable for use in the body of the snowmobile, in the protective storage/transport shell, or in a matching snowmobile suit.

Specifications
Your group will submit one sample of the polymer composite along with individual reports of test results to support claims that this composite is suitable for the intended application on the snowmobile.

Constraints
The composite must have a minimum of five layers and it must use at least one synthetic and one natural polymer. The adhesive(s) and coating(s) may be natural and/or synthetic and are not considered layers. If you decide on a polymer, glue, or adhesive not tested in the KSBs, then you must justify its use with test results before using it in your composite. The sample is to be 10 cm x 30 cm ± 0.5 cm.

Thickness requirements are:

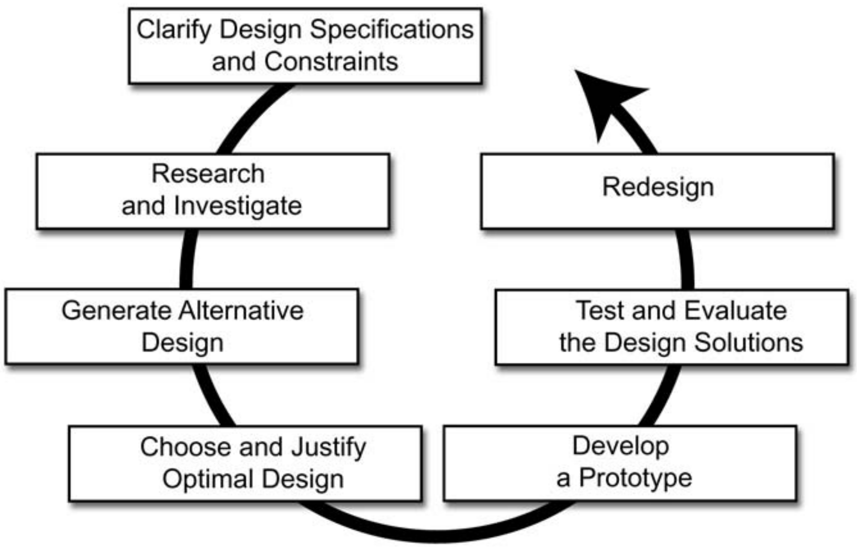
- Snowmobile body material – 0.5 cm
- Snowmobile storage/transport shell – 1.0 cm
- Snowmobile suit – 2.0 cm

The sample may be less than the maximum thickness.
Each composite should be waterproof or highly water-resistant.
The composite's flexibility should be appropriate for the intended use.

KSB T1: The Informed Design Loop

The informed design loop (see diagram below) is a method to achieve informed technological design based on knowledge and skills, rather than on trial and error alone. The loop involves repeatable phases that engage you in the design process and that can be repeated many times to improve your design.

INFORMED DESIGN LOOP



You are to work in a manner similar to that of professionals who do engineering design for a living. Engineers and other designers rarely follow these phases in order. Instead, they move back and forth from one phase to another as needed. You also are not expected to go through the phases in the same order each time you design something. Additionally, some decisions are made without complete knowledge and as a result phases must be revisited later on. The designer arrives at solutions, monitors performance against desired results, and makes changes as needed. Designing products or processes usually involves making trade-offs; seldom is true perfection obtained.

Further information on the phases of the informed design loop follows:

- *Clarify design specifications and constraints.* Describe the problem clearly and fully, noting constraints and specifications. Constraints are limits imposed upon the solution. Specifications are the performance requirements that the solution must meet.

- *Research and investigate the problem*. Search for and discuss solutions that presently exist to solve this or similar problems. Identify problems, issues, and questions that relate to addressing this Design Challenge.

- *Generate alternative designs*. Don't stop when you have one solution that might work. Continue by approaching the challenge in new ways and looking for even better solutions. Describe the alternative solutions you develop.

- *Choose and justify optimal design*. Select the optimal design from among the alternatives. Why is it the optimal choice? Be prepared to defend your selection. Use engineering, mathematical, and scientific data, and analysis techniques, to justify why the proposed solution is the best one for addressing the design specifications. This chosen alternative will guide your preliminary design.

- *Develop a prototype.* Make a model of the solution. Identify possible modifications that would lead to refinement of the design, and make these modifications.

- *Test and evaluate the design solution*. Develop a test to assess the performance of the design solution. Test the design solution, collect performance data, and analyze the data to show how well the design satisfies the problem constraints and specifications.

- *Redesign the solution with modifications*. In the redesign phase, critically examine your design and note how other students' designs perform to see where improvements can be made. Identify the variables that affect performance and determine which science concepts underlie these variables. Indicate how you will use science concepts and mathematical modeling to further enhance the performance of your design.

Develop your understanding

1. Review the informed design loop and explain how you might use the phases to guide efforts for your situation. Identify any procedural steps you would add, delete, or change. Defend your recommendation(s).

2. Pick one example of a product or system that was poorly designed. Explain possible reasons why the manufacturer might have allowed it to be produced with design flaws. Explain consequences (both positive and negative) that might result from a less-than-optimal design. Provide an example of a product or system that you think could benefit from an improved design.

KSB T2: Keeping a Design Journal

A Design Journal is a complete, permanent record of what you do each day as you work—it is a record of your activities and thinking. For scientists, engineers, and technicians, the lab notebook is a history of work that can be referred to if they need to replicate their work or prepare a report to explain their work to others. It is also a legal document used to support applications for patents or provide evidence of all laboratory tests for a company.

Your Design Journal should be neat, accurate, and written in pen. Pages should be dated so that it is easy to follow the order of your work. The lab notebook is necessary every time you work on the project. You are responsible for keeping your lab notebook in a safe and secure place so that it is available for each class period. Even though you may be working in a team, you should keep your own notebook containing a record of all:

- Predictions
- Tests and procedures, including equipment and supplies used
- Data: specific observations and accurate measurements with units
- Illustrations
- Observations
- Data analyses including graphs, charts, and calculations
- Notes
- Conclusions

At the end of each class period, remember that you need to have your Design Journal witnessed and signed off by another member of your team!

DJ – This icon will be displayed throughout the KSBs to indicate when to record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Displaying Observations and Data:
Strive to have your documentation

- Well organized
- Neatly written
- Thoroughly labeled (e.g., headings, sample numbers, trial numbers)
- Show proper use of units
- Include spaces for data/observations that are sized appropriately

The following are examples of data/observation displays. Carefully consider the data and/or observations you will record and decide on a method of organizing the information before you begin. These examples are not intended to limit you in displaying information. You may produce charts, tables, or other means of displaying data/observations of your own design.

Example 1 – All numerical data

Characteristics	Sample 1	Sample 2	Sample 3	Sample 4
Mass	12.35 g	7.88 g	5.02 g	11.10 g
Volume	14.1 mL			
Melting point	124.2 ^{o}C			

Example 2 – All numerical data

Sample #	Mass	Volume	Melting Point
1	12.35 g	14.1 mL	124.2 ^{o}C
2	7.88 g		
3	5.02 g		
4	11.10 g		

Example 3 – Combination of descriptive observations and numerical data

Sample #	Appearance	Mass	Distance	Impact (mass x distance)
1	Cloudy, thin	100 g	50 cm	5000 g cm
2				
3				
4				

Example 4 – A descriptive display of observations

Sample 1 – brown, soft, sinks in water, gives green flame test

Sample 2 – white, fairly hard, floats in water, sinks in alcohol

Sample 3 – yellow, sinks in water, orange flame, softens in acetone

Complete the following activity involving a polymer product to get you started using your Design Journal:

(activity starts on the next page)

Plumbers are familiar with a product known as Teflon tape (PTFE), which is available in most hardware stores. It is used to make a watertight seal between threaded iron pipes.

1. Cut a 15–20-cm length of this tape. Stretch it just slightly lengthwise. Make sure you have a firm grip on the ends, not just the corners. What do you observe?

2. Now stretch it slightly widthwise. What do you observe?

3. Try to stretch it lengthwise again.

4. Try to break it lengthwise. Use as much force as you need. What do you observe?

5. Try to break it widthwise. Use as much force as you need. What do you observe?

6. Cut a 15–20-cm length of this tape. Use a permanent fine-tip marker to write a secret message on the tape.

7. Have a partner hold it while you write lightly on the tape.

8. When your message is complete, wrap a small piece of clear tape around each end. Stretch tape widthwise to distort the message beyond recognition, *but not too far*. Hand it to a friend and have that person pull it lengthwise to unscramble the message. Re-distort the message and try again. What do you observe?

9. Think about the properties of Teflon tape that allow for this activity. Does the activity work with other types of flexible tapes? Try it. What do you observe?

KSB S1: Monomers to Polymers

Polymers are long-chain molecules made up of repeating smaller chemical units **(monomers).** In this KSB you will create and manipulate molecules to form

The BIG SIX recyclables. *Plastics are made up of building blocks called monomers, derived from petroleum or natural gas; therefore, these human-made plastics are called* synthetic *polymers. The monomers are chemically linked to form chains called polymers, or resins. Different combinations of monomers yield resins with special properties and characteristics. Six resins account for 97% of all plastic bottles and containers.*

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Part I: Recyclables 2 and 4

Step 1. From your pattern page cut out:
- Two carbon blocks
- Four hydrogen blocks
- One sigma bond
- One pi bond

Save the rest of your pattern page for use in further activities.

A carbon atom has four valence electrons and, therefore, will form four covalent bonds. Attach the two carbon atoms with a sigma bond and a pi bond. Place one hydrogen at the top and bottom of each carbon atom and attach with adhesive poster-hanging putty (e.g., Fun-Tak™).

You have now created a model of **ethene** (**ethylene** is the common name).
Draw your molecule model here. **DJ**

Notice that your sigma bond is thicker than your pi bond. Sigma bonds are stronger because there is a greater overlap of electron orbitals and the overlap is along the bond axis. Pi bonds are weaker because there is less orbital overlap and the overlap is perpendicular to the bond axis.

Step 2. Remove your pi bond that holds the carbon atoms together and slide your monomer next to that of the partner to your right. Link your monomer to his or hers with your pi bond. Continue this linking with a model from every member in your group. You have created the beginning of a polymer chain. (polyethylene, HDPE 2 or LDPE 4)

Draw three monomer models connected to demonstrate your polymer here. **DJ**

What you have just produced is an **addition polymer.** Polymers produced in activities A–D are addition polymers. *2*, called high-density polyethylene (HDPE), and *4*, called low-density polyethylene (LDPE), have the same monomer. The difference is in the amount of branching that occurs within the polymer. This difference gives rise to different applications. The formation of HDPE occurs under low temperature and high pressure with a special catalyst used in the formation of the long chains. These new catalysts enable scientists to make linear polyethylene chains consisting of 10,000 monomer units. Because side branches do not impede these long chains, they can be arranged so that more of the polymer chains are parallel. The highly ordered structure of HDPE gives it greater density, rigidity, strength, and a higher melting point than LDPE.

<u>Part II: Recyclable 3</u>

From your pattern page cut out the chlorine atom.
Reconstruct the ethene monomer unit model.

Remove the hydrogen in the lower-right-hand corner and *substitute* the chlorine atom. You have now created a model of the monomer **vinyl chloride.**
Draw your molecule model here. **DJ**

Repeat step 2 under Part I to create **polyvinyl chloride (PVC).**
Draw three monomer models connected to demonstrate your polymer here. **DJ**

<u>Part III: Recyclable 6</u>

Cut out one of the benzene molecules from your pattern page.
Reconstruct the ethene monomer model.

Remove the hydrogen in the lower-right-hand corner and substitute the benzene molecule.
You have now created the monomer **styrene.**

Draw your molecule model here. **DJ**

Repeat step 2 under Part I to create **polystyrene (PS).**
Draw three monomer models connected to demonstrate your polymer here. **DJ**

Part IV: Recyclable 5

From your pattern page cut out the remaining carbon atom and the three hydrogen atoms. This -CH_3 structure is called a **methyl** group. The fourth side of this structure has a bond that is available to attach to another atom or group. Reconstruct ethene and remove the hydrogen in the lower-right-hand corner of the molecule. Substitute the methyl group in its place. Look closely now: This structure contains three carbons so it now adopts the prefix (*prop-*) for three carbons in the chain. You have created **propene (propylene).**
Draw your molecule model here. **DJ**

Repeat step 2 under Part I to create **polypropylene (PP).**

Draw three monomer models connected to demonstrate your polymer here. **DJ**

Part V: Recyclable 1

Recyclable 1 is different than recyclables 2–6. It is formed from two monomers, an alcohol and an acid. **Esterification** is the name of the process in which an acid joins to an alcohol.

1. From page 2 of the pattern sheet, cut out:

two carbons
four hydrogens
two -OH (hydroxy) groups.

2. Create a dihydroxy alcohol by bonding the two carbon atoms together with a single bond. Place the four hydrogen atoms above and below the carbon atoms with TAC, and then attach the hydroxy groups on both ends of the carbon molecules.
3. Draw your alcohol here. **DJ**
   Name this alcohol (dihydroxy alcohols are commonly called **glycols**).

4. From page 2 of the pattern sheet, cut out the benzene structure and the two -COOH groups. The carboxylic acid group (-COOH) is the functional group for an organic acid. Cut out and place the other benzene ring in the center and attach a carboxylic acid group to opposite ends. Draw your acid here. **DJ**
   You have created terephthalic acid.

To make the polymer model, recall that an acid and an alcohol produce an ester and water.

5. Place your glycol model next to your acid model. The bonding takes place between the functional groups of both molecules. With scissors, remove the H from one of the hydroxy molecules of the alcohol. Then cut the OH group from the carboxyl group of the acid. With poster putty join the O atom from the alcohol to the C atom from the acid to create the ester. Join the remaining H with the OH to form water (H_2O). Repeat this process to continue forming the model of a polyester: **polyethylene terephthalate (PETE or PET).** The removal of water in this reaction makes this a **condensation polymer.** A condensation polymer is a polymer formed by the chemical combination of two organic molecules accompanied by the loss of water or other small molecule. Draw three (3) units of the polymer chain here. **DJ**

This process forms many natural polymers such as cellulose and chitin.
Industrial application of this process is set up to produce long chains of repeating monomers.

Connecting to the Challenge

In this activity you have modeled the six common recyclable polymers; you should be able to draw the molecular structure of each. Understanding the structure of polymers will help your design of the composite material and your justification for the polymers that you selected for the material.

KSB S2: Researching Polymers

In this activity you and students from other working groups will become "experts" in one aspect of polymers by researching a topic and preparing to share your "expertise" with your working group. This type of activity is called a "jigsaw" because you will work together with your group to put all the information pieces together.

Use the World Wide Web and printed materials to investigate your assigned topic about polymers. There will be a vast amount of information about polymers, so you should make a quick evaluation of each source to determine if it contains something of value before spending a great deal of time on a source that has little about your topic. When you decide to use information from a source, it is important that you record the source reference (URL, periodical issue and page, book bibliographical information, etc.). This will be useful later when you need to justify your choices for the polymers you use in your composite.

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Topics to Research: DJ
<u>(The following questions are given as guide questions; research should not be limited to these ideas.)</u>

History of synthetic polymers

1. Find anecdotal events that led to the discovery of certain polymers.
2. Become familiar with scientists and their discoveries in polymer chemistry.
3. What events led to the discovery of different polymers?
4.
5.

Sources of substances for synthetic polymers

1. How is crude oil related to synthetic polymers?
2. What is fractional distillation and is it important in the production of synthetic polymers?
3.
4.

As you research your topic, make note of information about the *properties* of the polymers.

Natural polymers and their uses

1. What are natural polymers?
2. Where are they most commonly found?
3. What are some important uses in the food industry?
   Health and beauty industry? Pharmaceutical industry?
4. Are there any natural polymers that are used as glues or adhesives?
5. *Properties*:

Synthetic polymers and their uses

1. Look up trademarks and find out what polymers, if any, are involved.
2. Are there any synthetic polymers that are used as glues or adhesives?
3. What uses do the Big Six recyclables have?
4. *Properties*:

Develop your understanding

1. List the source for your information in the first column below. Record the important information from the source in the second column. You are to find five or more items to enter in the information column for your topic. Your record can consist of notes, sentences, drawings, etc. **DJ**

Research Source	***Source Information***

[research information continued]

Research Source	***Source Information***

2. Review the information you have obtained with your “expert” group. Prioritize the information and plan how you will share it with your working group. Small group presentations can include posters, diagrams, web links from a home page, bookmark from the Internet, etc. **DJ**

3. Return to your working group. Within your group, organize the sharing of the information. Make your presentation clear and concise. Check to make sure everyone in your group has recorded and understands your information or can access it easily.

4. Record important polymer information from the other “experts” in your working group as they present in your cooperative group. **DJ**

Connecting to the Challenge

This information will assist you in deciding what materials to use in your Design Challenge. Is there any other information you might need that you would want to research now? Ask the “expert” in your group if s/he came across this information in the search. **DJ**

KSB S3: Identifying Polymers from Their Properties

The various models you made in KSB S1 show that polymers are small chains of repeating molecules called **monomers.** An entire polymer is referred to as a **macromolecule.** The properties of a particular polymer (and materials made from it) depend on both the properties of its monomers and the ways in which those monomers are linked together. Any structural change in the polymer or its monomers can result in significant changes in the chemical and/or physical properties of the polymer.

Polymers can be identified from their properties. One important skill you will need is to observe and measure the properties of polymeric materials (materials made from polymers).

Plastics are one very well known group of polymeric materials. In this KSB you will observe the properties of six plastics, and learn to relate their properties to the molecular structure of their constituent polymers. You will also learn to match the plastics with their resin, or recycling code on products.

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Safety

- Wear safety goggles and a laboratory apron at all times when in the laboratory. Also, secure long hair and any loose articles of clothing or jewelry. (These safety precautions apply to *all* polymer laboratory work you do.)
- Keep isopropyl alcohol, acetone, and corn oil away from open flames.
- Use forceps when placing a sample in a liquid for testing.
- Wash your hands after completing an activity.

Procedure

Create a data table in your Design Journal for this investigation. **DJ**
You will be observing six samples of plastic to determine:

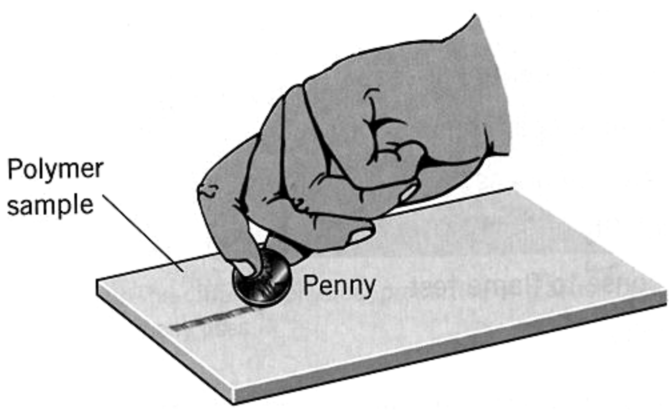
- how the material is used
- general appearance
- relative hardness
- flexibility
- response to flame test
- acetone test results
- density

Set up and run each test according to the operating procedures described below. Divide the different tests among the members of your working group. When all tests are completed, record everyone's observations in the data table in your Design Journal.

How the material is used: Fill in this information from your knowledge gained in KSB 3.

Appearance: Describe the color and the level of transparency (transparent, translucent, opaque) of the sample.

Relative hardness: The relative hardness of a material is determined by testing how easily it can be scratched. Use your fingernail, a penny, and a file to scratch the material's surface. To avoid scratching the surface of the table or desk, first place the material on a piece of cardboard.



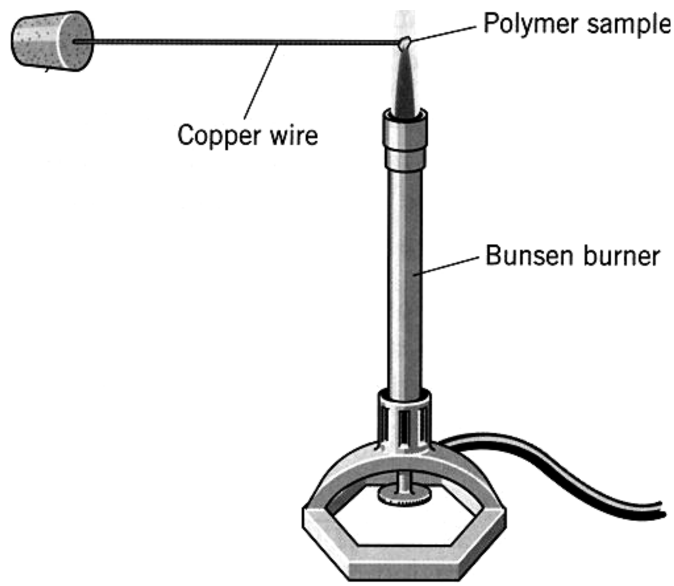
A scratch is defined as a groove that is visible to the naked eye. Those plastics that can be scratched by a fingernail are the softest. Next are those that can be scratched by a penny. The hardest are those that can be scratched only by a file.

Flexibility:

1. Fold a strip of the sample between your fingers and press together. Check for cracks, folds, or any color change in the sample.
2. Repeat the test after placing a strip of the material in ice water and then in very hot water. (Remember to use forceps when placing the sample in very hot water.)
3. Record your observations for the flexibility in all three temperatures in your data table.
4. Test all the assigned polymers for flexibility.

Flame test:

1. *Working under a fume hood,* hold the wire by the cork holder, and put the tip of a copper wire in the hottest part of the burner flame (inner blue cone) until it is red-hot.
2. Remove the wire from the flame. Use the heated tip to melt and remove a small blob of one of the plastics.



Testing a polymer sample for the color of flame it produces.

3. Return the wire and blob to the hottest part of the burner flame and note the color of the flame. Also note if smoke is produced and the color of the smoke.
4. Extinguish or quench the heated sample in a beaker of water.
5. Record your observations in the data table.
6. Test all of the assigned polymers.
7. Cool the wire and place it in the container provided.

Acetone test:

After the flame test, test the polymers that gave an orange flame with acetone.

1. Place the polymer samples to be tested in a shallow glass container in the hood.
2. Add enough acetone to cover the polymer samples.
3. Allow the samples to soak in the acetone for 5–10 minutes.
4. Remove the samples with forceps, place them on a paper towel, and check each to see if it has softened by trying to dent or scratch it with your fingernail.

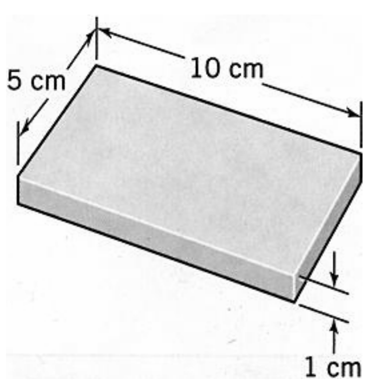
Density: Qualitative (relative densities)

1. Add about 50 mL of water to a 150-mL beaker. Place the plastic sample in the water. Does it sink or float? If it sinks, its density is greater than 1.0 g/mL. Record the density as > 1.0 g/mL and begin testing a different polymer. If it floats, it is less dense than 1.0 g/mL and you should go on to step 2.
2. Repeat the density test, using isopropyl alcohol. Remember to keep the alcohol away from a flame or a hot plate in use. The density of the alcohol is between 0.95 and 0.97 g/mL. If it sinks, its density is greater than 0.95 g/mL. Record the density as between 1.0 g/mL and 0.95 g/mL and begin testing a different polymer. If it floats, it is less dense than 0.95 g/mL and you should go on to step 3.
3. Repeat the density test, using corn oil. The density of corn oil is between 0.91 and 0.94 g/mL. If it sinks, its density is greater than 0.94 g/mL. Record the density as between 0.95 g/mL and 0.91 g/mL. If it floats, it is less dense than 0.91 g/mL. Record the density as less than 0.91 g/mL.
4. Repeat the density tests for all the assigned polymers.
5. When finished with the qualitative density testing, return the isopropyl alcohol and corn oil to the proper containers.

Density: Quantitative

1. Your group will be assigned one of the polymers for this measurement investigation.
2. Find the mass (in grams) of the piece of plastic using an electronic balance.
3. To calculate the volume of a regular-shaped, rectangular sample of plastic, multiply the length x width x height, measured in centimeters.

For example:



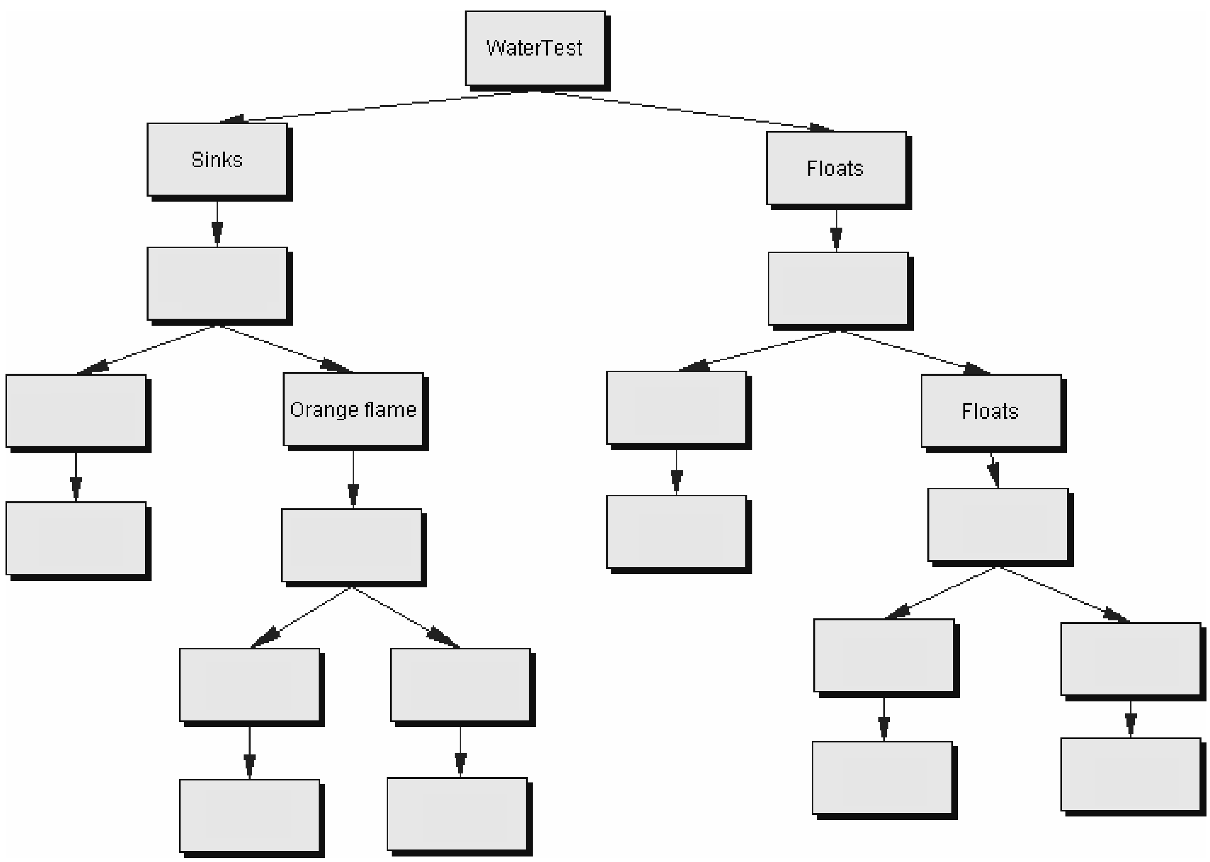
4. If the sample is irregular-shaped, determine its volume using the water displacement method:
   First, fill a 100-mL graduated cylinder to the 30-mL line, and then carefully add the sample. If the sample floats, gently push it under the water with a pencil. Record the new level of the water. The volume of the object is equal to the new

water level minus the original water level. Be sure no air bubbles cling to the sample.

5. Divide the mass of the object in grams (g) by its volume in milliliters (mL). The resulting value is the density of the object in g/mL.
   Note that for water 1 mL is equal to 1 cubic centimeter (cm^3).

Analyzing the data

1. Share and review the data your team has collected for each type of plastic. Use the Plastics Properties Flowchart and your data table to identify each plastic. Record the identities of the known plastics in the proper spaces on the flowchart below.



2. Compare your identifications with another team's to evaluate the usefulness of the flowchart. Construct a separate flowchart for your unknown.
3. Using the molecular structures of common plastics you drew in your Design Journal (KSB S1), discuss what connections there might be between the molecular structures of plastics and their properties. Record your connections. **DJ**

4. Look at the plastics recycling (resin) codes in your Design Journal (KSB S2). On the basis of your work in this activity, why do you think that particular plastics are used to make specific products? Record your reasons. **DJ**

Arriving at conclusions

What conclusions can you draw about the relationships you see between molecular structures and the properties of plastics?
Discuss your group's ideas with other teams in your class. Record your conclusions. **DJ**

Connecting to the Challenge

You have tested qualitative and quantitative properties of the six recyclable polymers. These properties will be important when you make decisions about the polymers that you choose for your composite polymer material.

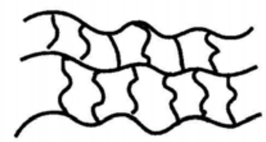
KSB S4: Thermoplastic and Thermoset Polymers

Two general types of polymers and their properties are:
Thermoplastic – Can be molded and remolded many times, using heat.
Thermoset – Once set, cannot be remolded.

Thermoplastic polymer chains are not connected to each other. They are only semicrystalline or *amorphous*. Thermoset polymer chains have numerous cross-links that bond them into rigid networks. Their structure is much more crystalline-like.

Linear random coil

Branched polymer



Cross-linked polymer

The amount of intermolecular force is very different in the different polymers. The linear random coil has much less force and the cross-linked polymer has much more. This is the primary difference between high-density polyethylene (HDPE) and low-density polyethylene (LDPE). (Note: You learned about these different polymers in KSB S1.)

You are to observe properties of a thermoplastic polymer, Friendly Plastic™, and a thermoset polymer, epoxy putty.

Safety

- Wear protective goggles throughout the laboratory activity.
- Thermoplastic activity: You will be using boiling water; observe normal precautions. Do *not* make a bracelet or ring out of the Friendly Plastic™. Also, do *not* put the plastic in your mouth.
- Thermoset activity: While working with the epoxy putty, do *not* put your fingers in your mouth or eyes. Clean your hands with rubbing alcohol when finished.

Procedure

DJ – This icon will be displayed throughout the KSB to indicate when to record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Part I: Thermoplastic Activity DJ

1. Pour about 300 mL of tap water into a 400-mL beaker; bring the water to a boil. Then turn off the burner or hot plate.
2. Hold one end of a strip of Friendly Plastic™, and dip the other end into the hot water until it softens. Keep it away from the sides of the beaker. Remove it from the water and—with *wet* fingers—grasp the softened end (it will not burn you). Dip the other end in the water until it is also softened.
3. Remove the strip from the water bath, and quickly mold the Friendly Plastic™ into a design of your own choosing—*not a bracelet or ring!* If the polymer becomes too hard, dip it in hot water to soften it.
4. Let the material cool on the countertop.
5. Thoroughly wash your hands before leaving the laboratory.

Part II: Thermoset Activity DJ

1. Obtain a 2-cm piece of epoxy putty from your teacher. Note that it is composed of two colored components.
2. Knead the putty until the two components are thoroughly mixed.
3. Quickly shape the putty into a design of your choosing.
4. Let the putty harden on a paper towel or piece of plastic bag. Do *not* let the putty harden on the countertop; it may be very difficult to remove.
5. As the putty is hardening, test its temperature with your fingertips. Does the sample change temperature? [Optional extension: Try heating the sample in a beaker of hot water and check flexibility.]
6. Thoroughly wash your hands before leaving the laboratory.

Parts I and II – Data Analysis and Concept Development DJ

1. In your own words, describe the differences between thermoplastic and thermoset polymers.
2. List at least ten product items of each type of polymer that you have used or seen.
3. What ideas do you have about what is happening at the molecular level when the plastic samples are heated?

Parts I and II – Implications and Applications DJ

1. Which of these two types of polymers could be more readily recycled?
2. In what applications would a thermoset polymer be most desirable?
3. Which polymer type would you choose for:
    a. Microwave dish
    b. Plastic bag
    c. Toothbrush handle
    d. Child's toy (doll or game)
    e. Dinnerware

Part III: Heat Distortion Test DJ

In this part you will investigate four (4) different polymers and their flexibility at different temperatures.
You will work with ten strips of each polymer:

Polypropylene (PP)
Polyvinyl chloride (PVC)
High-density polyethylene (HDPE)
Polystyrene (PS)

Also, you will need a hot plate, two 500-mL beakers, two thermometers, forceps, insulated pads, and paper towels.

1. Place 300 mL of room temperature water in both beakers and add a thermometer to each.
2. Place five (5) strips of one of the polymers in each beaker.
3. Place one beaker on the hot plate and begin to heat the beaker.
4. When the temperature reaches 40 ^{o}C, remove the beaker from the hot plate and place on an insulated pad.
5. Remove one strip from the heated beaker with forceps and remove one strip from the room temperature beaker.
6. Test the flexibility of both strips. (Does it bend? Is it brittle? Is it hard or soft?)
7. Also, look for changes in texture and appearance.
8. Record your observations.
9. Return the heated beaker to the hot plate and continue heating.
10. Repeat the testing of heated and room temperature strips for temperatures in 15-degree intervals. Your data should include results for 25 ^{o}C, 40 ^{o}C, 55 ^{o}C, 70 ^{o}C, 85 ^{o}C, and 100 ^{o}C.
11. Repeat the entire procedure for the remaining three (3) polymers.

Part III – Applications DJ

1. Why do you think the properties related to heat distortion are of importance to the polymer product industry?
2. What ideas do you have about what is happening at the molecular level when the plastic samples are heated?

Connecting to the Challenge

The types of polymers you choose for your composite could be thermoplastic or thermoset. Consider the characteristics you want for your composite and relate the desired characteristics to the properties you have just learned about for thermoplastics and thermosets. Think of the intended application of the polymer in the Design Challenge and relate what you have learned about heat distortion.

KSB S5: Preparation and Properties of a Cross-Linking Polymer

Solutions of the polymers polyvinyl alcohol (PVA) and polyvinyl acetate can be made into gels by addition of a borax solution. Borax cross-links the polymer chains. In this activity you will investigate interesting properties of gels. “Slime” is a polyvinyl alcohol polymer. “Gluep” is a polyvinyl acetate polymer.

You are to observe the effects of cross-linking polyvinyl alcohol and polyvinyl acetate chains with borax.

Safety

- Wear protective goggles throughout the laboratory activity.
- The polyvinyl alcohol and borax solutions are nontoxic, but wash your hands when finished. Keep the gel in a plastic bag; keep off clothes and carpets.

Procedure

DJ – This icon will be displayed throughout the KSBs to indicate when to record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Part I: Making “Slime”

1. Obtain 50 mL of PVA solution in a disposable cup.
2. Use a wooden stirring stick—a glass stirring rod does not work as well—and stir the PVA solution. Note its viscosity. Is it more or less viscous than water?
3. If desired, add one drop food coloring to the PVA. Stir well.
4. Measure 12.5 mL of borax solution in a 25-mL graduated cylinder.
5. Pour the borax solution into the PVA. Stir vigorously until the gelling is complete.
6. Scrape the gel from the cup into your hands. Pat and knead it thoroughly to completely mix the components.
7. Divide your mixture into four equal amounts and place each section on its own piece of aluminum foil. For 15 minutes, refrigerate one, freeze the second, leave the third at room temperature, and save the fourth for Part IV. After 15 minutes, record the temperature of the three environments and bring all three samples to your lab table. Have each team member take a different sample and perform the following tests. **DJ**

8. When handling the samples, it is important that none of the material gets in your mouth. Your hands should be washed immediately after handling the samples.
    a. Place a ball of the sample in the palm of your hand. Does it maintain its shape?
    b. Form the sample into a thick rectangular solid and hold it at one end. What happens?
    c. Form a ball and drop it on a smooth surface. Describe what happens.
    d. Try to make imprints on the surface of the sample with small objects, such as coins, paper clips, or the like. How long does an imprint last?
    e. After rolling the sample into a cylinder, pull it apart very slowly. Describe what happens.
    f. Reshape the sample into a cylinder and pull it apart quickly. What happens this time?
    g. Turn a paper cup upside down and place the sample (in a ball shape) on the top of a cup. Describe the behavior of the sample.
9. Save this polymer sample for Part III.

Part II: Making “Gluep” DJ

1. Mix 15 mL of white glue with 15 mL of water. Stir well. (Your teacher may have done this in advance.)
2. Measure two tablespoons (30 mL) glue mixture into a cup.
3. Add two teaspoons (10 mL) borax solution and stir vigorously. (The “gluep” will cling around the stick and can be pulled out, usually in one blob, without much being left in the cup.)
4. Knead the “gluep” well, and repeat steps 7 and 8 under Part I.
   [Note: “Gluep” will NOT be tested in Part III.]

Parts I and II – Implications and Applications DJ

1. Is covalent or hydrogen bonding responsible for the cross-linking?
2. Why is borax [$B(OH)_4$- is the active ingredient] an effective cross-linker?
3. Draw a representation of the polymer chains:
   a. before cross-linking
   b. after cross-linking

(Be sure to include some water molecules in your drawing; after all, both solutions are 96% water!)

4. Compare the results of the tests on the cross-linked polymers. In general, what similarities do you notice between their properties? What differences? How might you account for this?
5. What effect did differences in temperature have on the properties of the two cross-linked polymers? How could you account for any differences?

Part III: Effect of Acid and Base on "Slime" DJ

1. Place a dime-sized piece of slime on a watch glass or petri dish. Add 2 M HCl drop-by-drop, stirring well with the stick after each drop. When a change is noticed, record your observations.
2. Add 2 M NaOH drop-by-drop to the same sample, stirring well with the stick after each drop. When a change is noticed, record your observations. (Repeat the procedure, if you wish.)
3. Thoroughly wash your hands before leaving the laboratory.

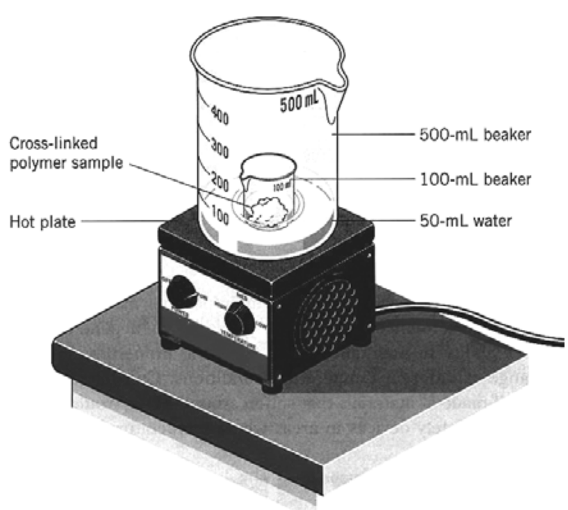
Part III – Data Analysis and Concept Development DJ

1. How many drops of HCl were necessary to "break the gel"?
2. How many drops of NaOH were required to re-gel the polymer?
3. Write the equation for the reaction of HCl with NaOH.

Part IV: Thermal Sensitivity Test DJ

You will gather data on how temperature can affect viscosity of polymer materials.

1. Taking the sample that you saved in Part I or Part II, divide the cross-linked material into three equal-sized pieces. One will be heated, one will be chilled, and one will be kept at room temperature.
2. Prepare a hot water bath by placing a 500-mL beaker containing 50 mL of water on a hot plate. Place a thermometer in the water. Place one of the pieces of sample material in a small beaker and place the beaker in the water bath. Your complete setup should look like the diagram below.



3. Prepare a cold water bath by putting 50 mL of ice and water in a second 500-mL beaker. Place a thermometer in the water. Place another piece of the sample material in a small beaker and place the beaker in the water bath.

4. With forceps, hold the remaining piece of sample material at room temperature, over the opening of an empty film canister or small cup. Allow the sample to flow from the forceps into the cup or canister. Record in the data table the amount of time it takes for the entire sample to flow into the cup.
5. Observe how well the sample fills the interior of the container. Does it touch the walls of the container on all sides? Or is there air space between the sample and the walls of the container? A lot of space or a little? Record your observations.
6. Your teacher will tell you the appropriate temperatures for your other two samples. (Each team in the class will be testing at different temperatures to provide data for a range of temperatures between 0 ^{o}C and 100 ^{o}C.)
7. Repeat steps 4 and 5 with the samples in the cold and hot water baths. Be sure to record the temperature of the baths when you remove the samples. Record your observations.

Part IV – Data Analysis and Concept Development DJ

1. At what temperature(s) did the sample material fill the container most nearly completely?
2. What does this tell you about the effect temperature has on the material's properties?
3. What ideas do you have about what is happening at the molecular level to the sample material at different temperatures? How might you test your idea?
4. Do you think the results would be the same or different if more cross-linker had been added to the glue mixture? Why?
5. In the manufacture of polymer products, why is it important to know the temperature at which a material flows?

Connecting to the Challenge

Considering the amount of cross-linking in polymers may be important in your choice of plastic in your composite.
How does thermal sensitivity relate to the design of your composite?

KSB S6: Which Polymers "Hold" Water?

Plastic grocery bags maintain their strength even when wet. Paper bags, on the other hand, lose much of their strength when wet. Intermolecular force accounts for the differences in the way plastic and paper interact with water.

DJ – This icon will be displayed throughout the KSBs to indicate when to record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Cellulose paper contains a polymer of glucose. Glucose is very soluble in water. Devise a method that would allow you to determine how much glucose will dissolve in water. Write out explicit steps in your Design Journal so that a classmate could follow your instructions. What units would your answer have? **DJ**

Develop your understanding

Part I: "Getting wet"

1. a. We know that glucose is soluble in water. Do you think cellulose, a polymer of glucose, would be soluble in water? Support your prediction. **DJ**

   b. Test your prediction by placing cellulose in water. Describe your results. **DJ**

2. Cellulose is produced by the action of enzymes as plant cells grow. Enzymes are examples of natural catalysts. An enzyme called *cellulase* can break down cellulose. If cellulase were added to your cellulose-water mixture, would you expect to see any changes? If so, what might you see? Provide support for your response. **DJ**

3. Using a sample of iodine in water:

   a. What is the color of the iodine-water mixture? **DJ**

   b. What changes do you observe when some oil is added to the iodine-water mixture? Devise an explanation for your observation. What does this have to do with solubility? **DJ**

Part II: Why do some polymers "hold" water and some do not?

Polarity

In the previous investigation we learned that some compounds, such as glucose, dissolve readily in water, while others, such as cellulose, do not. Although it is easy to determine water solubility by mixing a compound with water, it is more convenient to be able to predict water solubility without actually testing it. Such predictions are possible if we use electronegativity values along with information about molecular shapes.

Electronegativity is a measure of the tendency of an atom to attract bonding electrons to itself. The greater the electron negativity difference between the two atoms, the more polar the bond.

The molecular polarity is important because polar compounds tend to dissolve in other polar compounds, and nonpolar molecules tend to dissolve in nonpolar compounds. This is the basis for the phrase "like dissolves like."

1. Each of the molecules listed below is a monomer used in making polymers. Use your knowledge of bonding theories to predict and sketch the shape of each monomer molecule. Identify all the polar bonds in the molecule and use bond polarity and shape to predict whether each compound below forms polar molecules or nonpolar molecules. **DJ**

   (a) 1-propanol
   (b) CH_3NH_2
   (c) $CH_2{=}CHCH_3$
   (d) CH_3COOH
   (e) 1-pentanol
   (f) glucose
   (g) 1-propanol
   (h) 1,1-difluoroethene
   (i) Cis-1, 2-difluoroethene
   (j) Trans-1, 2-difluoroethene

Cis and Trans

Cis – Literally means *on the same side*. The term *cis* is used to describe isomers in which two substituent groups are attached on the same side of a double bond in an organic molecule.

Trans – Literally means *across from*. The term *trans* is used to indicate geometric isomers in which two groups are attached to opposite sides of a double bond in an organic molecule.

2. Which of the above compounds will most likely dissolve in water? Support your predictions using chemical concepts. **DJ**

3. Which of the following will dissolve in oil? Support your predictions using chemical concepts. **DJ**

Applying your ideas DJ

1. Cut out a piece of paper grocery bag 10 cm x 20 cm. Draw a pencil line from top to bottom down the middle of the piece of bag. Cover the left half of the paper piece with aluminum foil and spray the exposed half with Scotchgard™ and let it dry. Now spray the whole piece of paper bag with water. Observe the results and explain what happened. [Hint: The chemical structure of Scotchgard™ is $(-CF_2-)_n$.]

2. Cotton is almost entirely cellulose. How would Scotchgard™ help prevent stains on a chair upholstered with cotton fabric? (Use chemical concepts in your explanation.)

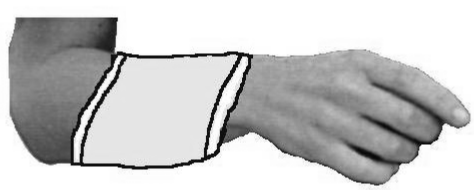
Perspiration inspiration

People lose moisture through evaporation from pores in the skin. When you are hot and begin to sweat, your rate of perspiration speeds up with the effect of cooling your body. Skin moisture can evaporate rapidly in a dry climate, even when you are not sweating. On average, an adult loses about one liter of water a day. When working hard and burning energy that produces heat, a person's water loss quickens proportionally.

Materials

One plastic bag per student, or plastic wrap
Scissors
Masking tape
Paper and pencil

1. Cut the plastic bag into a single-layer square large enough to fit comfortably around your forearm. Place the piece of plastic around your forearm and tape it securely (but not too tightly) at top and bottom.



2. Wear the plastic over your forearm for at least ten minutes. Meanwhile, in your group, take and record your pulse and respiration rates. Then walk up and

down a flight of stairs five times (if the school has no stairs, walk in the hallway). Record your new pulse and respiration rates. **DJ**

3. Next, run in place for two minutes and then record pulse and respiration. **DJ**

4. After the exercise, note whether the plastic contains any liquid water released by your skin as it performed respiration and perspiration. **DJ**

5. Take the bag off and feel the moisture on your skin where the plastic had been. Note the moisture level of the skin that was under the plastic as compared to skin exposed to air during the ten minutes. **DJ**

Questions: DJ

1. What is the effect of moisture evaporating on your skin?
2. How much fluid does a person need to consume each day to replace regular moisture loss?
3. In addition to water, what other essential materials do we lose through perspiration?

Connecting to the Challenge

How would the ideas presented in this KSB help you in your design project?
What specific factors from this activity should be kept in mind when choosing polymers for your composite?
What inferences can be made about natural and synthetic polymers from this KSB that would help you decide about materials for your composite?

KSB T3: Impact Effects: "Dropped Dart Tests"

Sheets or films can be tested for impact resistance in a variety of ways. One method is called a "dart" test. This involves mounting the sheet or film securely on the top of a large metal can and dropping a dense weight on the sheet or film to determine the breaking point.

Safety: Follow all standard safety procedures during this activity.

Materials

Large can (height and diameter at least 10 cm; e.g., a coffee can)
Wide rubber bands
Meterstick or tape measure
Various plastic film and sheet samples (e.g., trash bags, food wrap, sections of bleach bottle, plastic food container material, grocery bags, dry cleaning bags)
"Darts": various sizes of weighted balls, smooth weights, or bolts with smooth and rounded tops

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Part I

Develop a dart test in which the <u>weight</u> of the dart *changes* while the <u>height</u> remains *fixed*. Determine and record the impact needed to break a variety of plastic film and/or sheet samples. **DJ**

Part II

Develop a dart test in which the <u>height</u> of the fall *changes* while the <u>weight</u> of the dart remains *fixed*. Determine and record the impact needed to break a variety of plastic film and/or sheet samples. **DJ**

To calculate the <u>impact</u>, multiply the mass of the dart by the height from which it was dropped.

mass x distance = impact

Data analysis

Summarize the results of your impact tests of different films and/or sheets of polymer. Include, if possible, the actual polymer name for each different film and/or sheet. Your summary should be anecdotal and in graph form. **DJ**

An additional test

Testing impact durability:
Design and carry out a procedure to test one of the films or sheets to determine how many times a dart dropped from a specific height can impact the sheet or film before the dart punctures the material. Do trials having low impact and record the data. Now, increase the height or weight to generate trial data for high impact. **DJ**

Analyzing the results

Summarize the results of the durability tests you have performed. Include the polymer name for the sheet and/or film you have tested. Your summary should be anecdotal and in graph form. **DJ**

Connecting to the Challenge

Impact resistance and durability are important factors in recreational products. Consider your results from this KSB when choosing the polymer material for your composite.

KSB T4: Glue: Holding It All Together

"Glue" may be many different substances. It is typically used to bond one material to another or to join two pieces of the same material. Even water can act as glue for a short time, holding two pieces of paper together. This is due to the intermolecular forces between water and the cellulose fibers in the paper. Glues work because of the bond-like forces that can occur between two materials.
Durable adhesives are more desirable for bonding two surfaces together. Strong glues contain molecules with strong intermolecular attractions for each other and for the material to be connected. This can be as simple as gluing cutouts on a collage or as critical as gluing parts for a huge passenger airplane.

Safety

- Follow all standard safety procedures while working on this activity.
- Keep the glues away from flame, heat, or sparks.
- Use caution when using scissors or other cutting tools.

DJ – This icon will be displayed throughout the KSBs to indicate when to record information in your Design Journal. You may enter information at any point in your work, but the icon will indicate areas where the information is required.

Part I: Evaluating Glues

Your instructor will assign each member of your group four (4) glues to test.

- Using a sheet of aluminum foil about 60 cm long, place two penny-sized samples of your glue (about 1.5 cm in diameter) on the foil.
- Space the two samples about 3 cm apart and spread the second sample with a flat wooden stick (e.g., a tongue depressor) to form a thin layer.
- Record the time when you place each sample on the foil. **DJ**
- Carefully check the glue sample for odor by wafting any fumes toward your nose. Record the presence or absence of odor for the glue sample. **DJ**
- Allow the samples to dry.
- Check the samples frequently during the period. Some samples may need to dry overnight.

Qualitative Data

- Carefully peel the glue from the foil.
- Did the glue dry clear or opaque? Hold the sample up to the light from a window or overhead lights. Does it allow light through or does it block the light? Record your observations. **DJ**

- Is the dried glue rigid or flexible? Gently bend the piece of dried glue. Record your observations. **DJ**

- Is the dried glue soluble in water? Place a small piece of it in a test tube one-fourth full of water. Stopper the tube and gently shake the tube for 3 minutes.

Check to see the extent glue is dissolved in the water. Record your observations. **DJ**

Quantitative Data

- Drying time: Record the drying time for each glue in appropriate time units. For some glues, the time will be "overnight." **DJ**

- Measurement of samples before and after drying: Measure in centimeters (cm) and record the length and width of the samples before and after drying. **DJ**

Part II

Now each member of your group should take samples of composite layer materials and glue the following combinations:

- ❖ two natural polymers
- ❖ two synthetic polymers
- ❖ two synthetic/natural combinations

Record the combinations. **DJ**

Use the four glues assigned to your group by your instructor for this part.
You will share data about the glues with the other groups at the end of the activity.

- Cut out samples of the materials you will attempt to glue together. Cut the samples 5 cm x 2 cm.
- Mark a pencil line 1 cm from the end of each strip.
- In the 1-cm end area, apply a thin layer of the glue to each piece of material you will try to bond.
- Place the two pieces of material together, overlapping the glued areas.
- Cut out another set of samples of the same size.
- Glue this set over the entire area of the strips and lay them together to form two matched glued layers.
- Lay them on a foil sheet to dry.
- Set the foil and samples aside to dry overnight. Weight may be added to hold the pieces together.

Qualitative Data **DJ**

- Check the appearance of the materials in the area bonded. Record observations.
- How does the new bond affect flexibility? Gently try to bend the bonded area. ***Do not*** make a permanent bend in the sample.

Quantitative Data **DJ**

- Punch a hole in one end of the 1-cm overlapped bonded strips 1 cm from the end.
- Attach a spring scale to the strip, using the hook.
- Hold the sample and scale horizontally. While one person holds the scale and is ready to read the force, a third person pulls slowly on the opposite end of the bonded strip. Read the force at the point the bond breaks or the material itself breaks. If the scale reaches its maximum, switch to a scale with a higher force limit. Record the force at the breaking point and note which failed: the bond or the material.
- Repeat for all of the 1-cm overlapped bonded strips.

The following tests are for materials that are considered to be rigid. Do not test fabrics, films, or other flexible materials during these tests.

- Modify a butterfly-type paper clip so the two pointed ends match. The clip should now be approximately triangular in shape.
- Slide a rigid two-layer bonded strip into the modified butterfly-type paper clip.
- One person holds the ends of the strip and another person attaches the spring scale to the clip. Pull gently on the spring scale and note the force needed to make a permanent bend in the strip. Record this force.
- Repeat for all of the rigid two-layer overlapped bonded strips.

Check to see that all members of your group have the data for these tests in their Design Journal. Your instructor will arrange for all groups to share their data with other groups. Remember, other groups may have used other materials and glues. Record any new findings from the tests gained through your sharing with other groups. **DJ**

Connecting to the Challenge

The results of the glue testing should provide valuable information for making decisions about how you will ”connect” the layers of your composite. You need to take into account the strength, appearance, thickness, and flexibility of the glue-material samples to decide what to choose for your intended recreational product. Have a discussion in your group about the glues and adhesives you may want to use for your composite.