TEACHER INSTRUCTIONS

Ceramic Processing: Slip Casting

Objective: Students will learn the fundamentals of slip casting and be able to think critically about why slip casting is used.

Background Information: Historically, ceramic materials in the form of clay figurines and pots were the first man-made materials over 10,000 years ago, and maybe even as long as 25,000 years ago, according to Sass. We've come a long way since then, and now use ceramic materials in applications anywhere from artificial bones, to light-weight body armor, to coatings on the leading edges of hypersonic vehicles. Since ceramics have very high melting temperatures, they are not as easy to make into complex shapes as metals or plastics that are typically melted, poured into a mold, and let cool to achieve the final object. Ceramic materials also possess very high hardness, meaning they are difficult to cut into complex shapes, another method used to form complex shapes of metals and plastics. One of the more sophisticated methods of manufacturing ceramics into complex shapes that we use today is called slip casting. *Slip casting* is a method used to make the shape of a coffee cup, for example, without the use of heat. The heat is usually applied after you make the material into the shape you want in ceramic processing – that process is called sintering (refer to our Sintering: Grain Boundaries, Interfaces, and Porosity lesson for more information).

By mixing a fine ceramic powder in water, along with some chemicals that help the powder to disperse throughout the liquid, you create what is called a *slip*. A slip is fluid, but contains solid particles. Think of it like silt in a river, or sand at the beach when the waves reach your sand castle. The liquid allows the solids to move around. For this lab, you will be using a *porcelain* slip. Porcelain is a mixture of clays and minerals.

Because the ceramic powder isn't dissolving in the water, when you remove the liquid, the solid is left behind. In slip casting, the slip is poured into a *mold* that removes some of the liquid from the slip near the mold wall. This occurs because the mold is porous and the liquid wicks into the pores by *capillary action*. This is the same force you see when you insert your straw into a drink- the liquid is drawn up the straw by capillary action. The molds used for slip casting are usually made of *plaster*. They are formed by mixing gypsum and water in a 4:3 ratio and allowing it to harden around a replica of the shape you hope to produce. This results in a cavity shaped like your final product that you can then pour the slip into.

When the liquid is removed from the slip in the mold, the solid powder material is left in the shape of the mold. Once the powder is completely dried and removed from the mold, we are left with what is called a green body. A *green body* is extremely fragile, but holds its shape well enough to move it to a furnace or kiln for sintering. One of these furnaces will reach temperatures of almost 1,400°C. The green body is transformed by the heat into a dense, strong part through the sintering

process. This firing step is essential to making useful ceramics. Oftentimes the green body is coated in a glaze before firing to give it a smooth exterior and make it safe to eat or drink out of. The slip casting process is illustrated below in Figure 1.

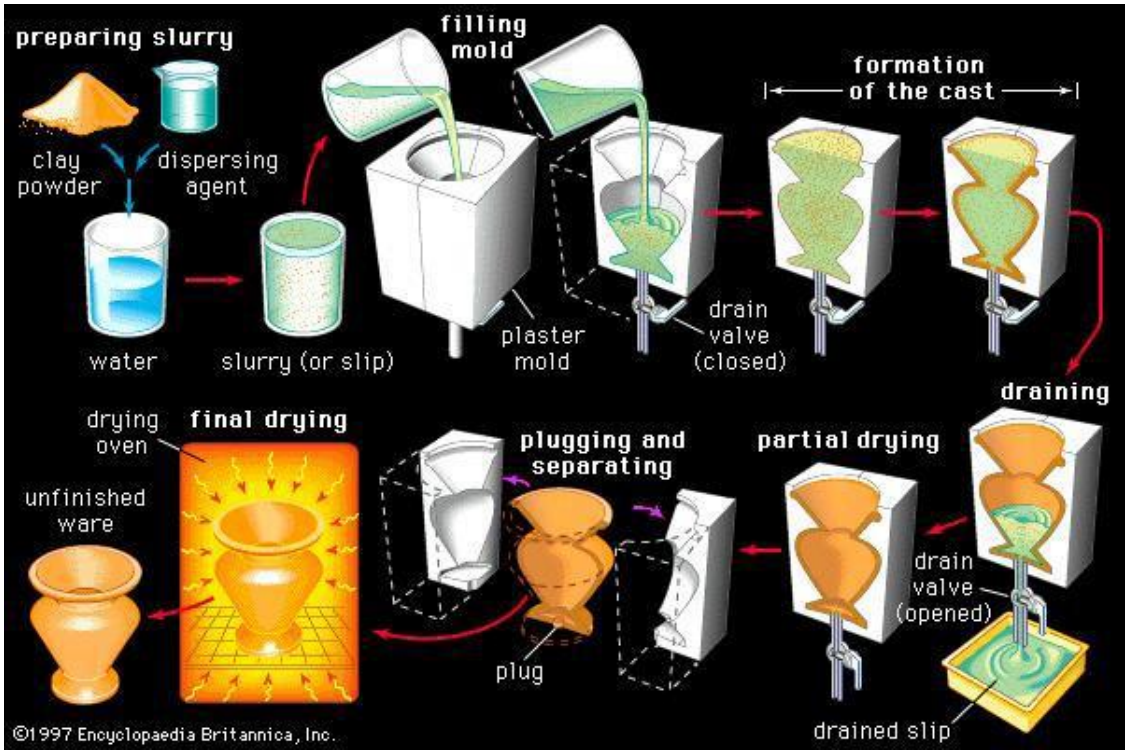

Figure 1: Schematic showing the steps used in slip casting. First the slip is prepared by mixing the ceramic powder with a liquid. Next the slip is poured into the mold which absorbs the liquid out of the slip leaving a thin wall of powder along the mold wall. The access slip is removed and the green body can then be removed from the mold. Finally, your part is placed in a furnace to be sintered into the final dense object. (https://www.britannica.com/technology/traditional-ceramics)

Title: How are complex ceramic shapes made?

Lab Description: In this lab, students will gain hands on experience in slip casting a small ceramic object. You can pre-make the molds then have the students slip cast their own part. This can be done in small groups, or individually depending on how many molds are made. If you have access to a high temperature furnace, you could also sinter the part after slip casting (recommended temperature is 2205° F; instructions are included with premade slip).

Keywords:

slip casting: A method used to make complex shaped ceramics without having to melt them.
slip: A liquid suspension of ceramic particles in water.
porcelain: A ceramic, which is often used in cooking and dishware, made up of a mixture of clays.
mold: The shaped cavity which is used to form another material into the desired shape.
capillary action: The ability of a liquid to flow into small spaces or tunnels.
plaster: A light, fragile, porous material often used in construction and art, with chemical formula $CaSO_4 \cdot 2H_2O$.
green body: A dry, unfired ceramic composed of tightly packed together powders.

Materials List:

1 – 8-pound container of plaster of paris powder (1 container makes 6-8 small molds). Can be found at amazon, Walmart, or your local craft store.

1 – 1 gal. premade porcelain slip. Can be found on amazon (brand is Amaco).

Plastic or aluminum trays – should have the same number as the number of molds you want to make, and should be just slightly larger than the figurines you're using. Small Tupperware containers work great for this.

Plastic cups/containers – to weigh powders in for the mold making, and for students to pour the premade slip into prior to casting it in their mold.

Small figurines or pots – small pots, plastic figurines, etc. to shape the molds.

Stir rod/spatula – to mix the plaster to make the molds.

Water – to add to the plaster of paris.

WD-40 or other lubricant – to coat the figurines with before pouring the plaster to make them easier to remove.

Paper towels/cloth – to clean up any spills.

Scale/balance – to weigh the plaster.

Gloves and safety glasses – to protect your hands and eyes.

Safety Precautions: When mixing powders, be cautious not to breathe in the loose powders (a dust mask can be worn for protection). Always wear safety glasses. If using heat lamps to dry molds/parts, the lamps will be hot so caution should be used when around them.

Instructions:

Making plaster molds (for Teacher)

1. It may be helpful to view this video to give you an idea of what the process will be like: https://www.youtube.com/watch?v=GIwNMYOIb6E
2. Choose small pots or figurines to create the cavity for the slip cast in the mold, and choose how many molds you need to make.
3. Prepare your work area. Set out the plastic or aluminum trays/containers that you will use to pour the plaster into. It will also be helpful to coat the trays and figurines with a lubricant (WD-40 or any oil works).
4. Make your plaster for the mold by mixing water and plaster of paris (gypsum) powder in a 3:4 weight ratio (i.e. 30 grams of water to 40 grams of plaster of paris).

- This weight ratio of water to powder is very important so be sure to weigh carefully. It is also important that the two are well mixed.
- The amount of plaster you will need to mix depends on the size of the mold (dictated by the size of the figurine you use) and how many you're making. For reference, ~3.4 kg (7.5 lbs.) of plaster of paris when mixed with the appropriate amount of water, will make approximately a 6" x 6" x 6" cube. If you use a figurine smaller than a 1" cube, this can make 6+ molds.

5. Place the pot or figurine open-end down in the tray.
6. Carefully pour the plaster in the trays around the figurine.
7. Allow the molds to dry at room temperature for 30-45 minutes.
8. Remove the molds from the trays and remove the figurine from the mold (it might be helpful to use a knife to chip away some of the mold to remove the figurine, but be careful as the mold is brittle and can potentially break!).
9. Place under a heat lamp or in a sunny window for 2-3 days (used to help ensure drying of the mold).
10. You may want to try slip casting a part yourself before having the students to make sure the molds were made properly.

Slip casting a part (for Students)

1. It may be helpful to watch this tutorial video to give you an idea of what the process looks like: https://www.youtube.com/watch?v=y7IXhgQdRkc
2. Weigh your mold and record its weight.
3. Pour the pre-made porcelain slip into the cavity (careful not to overflow).
4. Observe the edge of the slip near the mold walls – you should be able to watch the material solidifying from the edges inward.
5. Once desired part thickness is reached (5-10mm, does not have to be exact, usually takes between 10-15 minutes), carefully pour out excess slip into waste container.
    - Here you can have different groups/students leave their slip in the mold for longer to achieve different part thicknesses.
6. The casted part should now resemble the cavity in the mold.
7. Carefully weigh the mold and casted part and record.
8. Place the mold (with the slip casted part still in the cavity) under a heat lamp or in a sunny window for 30-60 minutes to dry the part.
9. Remove the part from the mold (this can be done carefully to save the mold, or the mold can be broken to remove the part easier).
10. Weigh the part and record.
11. Let piece sit overnight to ensure that it dries.
12. Now you have a slip casted part!

Lab Hints & Troubleshooting: If the mold seems very dense and hard and doesn't absorb water when trying to slip cast the part, there was probably too much water used when mixing the plaster of paris powder and water. If either the mold or casted part seem to crumble away after drying it for the instructed time, it may need to be set out to dry for longer. If you are having trouble removing the final dried parts from the mold, a small air gun (or hair dryer on low to no heat) can be used to blow on the part which will help it detach from the mold wall more easily.

Clean up/Replacement Parts: Clean any spills you may have had of the slip, and throw away disposable cups used to hold the slip. If molds were handled carefully, they can be stored and reused as long as they are fully dried out between uses.

TEACHER DISCUSSION QUESTIONS

Ceramic Processing: Slip Casting

Discussion Questions to Ask Before the Lab

1. What are some things that we use in our every-day lives that are made of ceramics like porcelain? Remember, a ceramic is typically a hard, brittle, heat-resistant material.

   Discussion: Bowls, plates, mugs, baking dishes, tiles, sinks, and toilets are just a few things we use every day that are made of ceramics. In fact, many of these pieces are made through industrial slip casting!

2. Ask students how they think those ceramics are made? For example, how would you make a ceramic pot or cup?

   Discussion: Students may think these objects are made with a pottery wheel, or by molding/sculpting. Remind them that these ceramic dishes and cups are typically made in bulk to make them more affordable, and would take a very long time to do by hand in large quantities. Slip casting is used as a quicker process that can make large quantities in various shapes.

3. To help students understand how the water is being removed by the mold: Why does a sponge absorb water and water spread up a paper towel if you dip the end of it in water?

   Discussion: The driving force for these porous objects absorbing water is capillary action. These are adhesive forces that pull water into small channels, like a drinking straw or small pores in a sponge or paper towel. A similar analogy to the water from the slip being wicked into the mold is when water from wet grass is wicked into the cuffs of cotton pants; water moves from areas of high concentration to low concentration.

Discussion Questions to Ask After the Lab

1. What advantages does this technique (slip casting) have over using a pottery wheel or hand-shaping some clay? Can you think of any limitations to using this process?

   Discussion: Advantages to the slip casting technique are that it is a much faster process that can be used to make several different shapes. The thickness of the part is also easy to vary by keeping the slip in the mold for shorter or longer times. Remind students that shorter, easier processes mean less expensive parts. Using the same mold for creating many parts also insures the same dimensions and features of each part. There are limitations to using slip casting however. For example, it can be hard to keep the thickness of the part uniform around tight corners, which can be a problem for small parts with sharp features. Additionally, molds that are fragile and break after one or two uses can add cost to the process as you will continually have to make or buy more molds.

STUDENT LAB HANDOUT

Ceramic Processing: Slip Casting

Background Information: Historically, ceramic materials in the form of clay figurines and pots were the first man-made materials over 10,000 years ago, and maybe even as long as 25,000 years ago, according to Sass. We've come a long way since then, and now use ceramic materials in applications anywhere from artificial bones, to light-weight body armor, to coatings on the leading edges of hypersonic vehicles. Since ceramics have very high melting temperatures, they are not as easy to make into complex shapes as metals or plastics that are typically melted, poured into a mold, and let cool to achieve the final object. Ceramic materials also possess very high hardness, meaning they are difficult to cut into complex shapes, another method used to form complex shapes of metals and plastics. One of the more sophisticated methods of manufacturing ceramics into complex shapes that we use today is called slip casting. *Slip casting* is a method used to make the shape of a coffee cup, for example, without the use of heat. The heat is usually applied after you make the material into the shape you want in ceramic processing – that process is called sintering (refer to our Sintering: Grain Boundaries, Interfaces, and Porosity lesson for more information).

By mixing a fine ceramic powder in water, along with some chemicals that help the powder to disperse throughout the liquid, you create what is called a *slip*. A slip is fluid, but contains solid particles. Think of it like silt in a river, or sand at the beach when the waves reach your sand castle. The liquid allows the solids to move around. For this lab, you will be using a *porcelain* slip. Porcelain is a mixture of clays and minerals.

Because the ceramic powder isn't dissolving in the water, when you remove the liquid, the solid is left behind. In slip casting, the slip is poured into a *mold* that removes some of the liquid from the slip near the mold wall. This occurs because the mold is porous and the liquid wicks into the pores by *capillary action*. This is the same force you see when you insert your straw into a drink. The liquid is drawn up the tube by capillary action. The molds used for slip casting are usually made of *plaster*. They are formed by mixing gypsum and water in a 4:3 ratio and allowing it to harden around a facsimile of the shape you hope to eventually produce. This results in a cavity shaped like your final product which you can then pour the slip into.

When the liquid is removed from the slip in the mold, the solid powder material is left in the shape of the mold. Once the powder is completely dried and removed from the mold, we are left with what is called a green body. A *green body* is extremely fragile, but holds its shape well enough to move it to a furnace or kiln for sintering. One of these furnaces will reach temperatures of almost 1,400°C. The green body is transformed by the heat into a dense, strong part through the sintering process. This firing step is essential to making useful ceramics. Oftentimes the green body is coated in a glaze before firing to give it a smooth exterior and make it safe to eat or drink out of. The slip casting process is illustrated below in Figure 1.

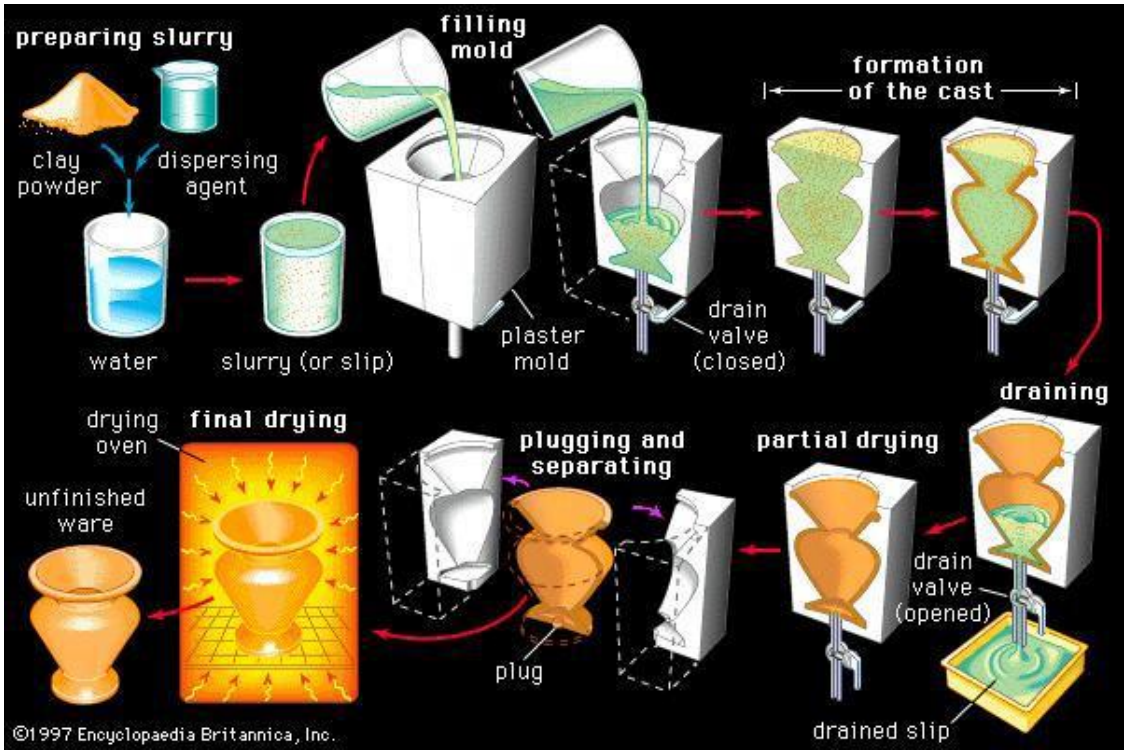

Figure 1: Schematic showing the steps used in slip casting. First the slip is prepared by mixing the ceramic powder with a liquid. Next the slip is poured into the mold which absorbs the liquid out of the slip leaving a thin wall of powder along the mold wall. The access slip is removed and the green body can then be removed from the mold. Finally, your part is placed in a furnace to be sintered into the final dense object. (https://www.britannica.com/technology/traditional-ceramics)

Title: How are complex ceramic shapes made?

Lab Description: In this lab, you will slip cast a small ceramic object.

Keywords: Slip Casting, Slip, Porcelain, Mold, Capillary Action, Plaster, Green Body

Materials List:

1 – mold used to make the part in.

1 – cup of premade porcelain slip.

Paper towels/cloth – to clean up any spills.

1 – pair of gloves and eye glasses.

Safety Precautions: Wear safety glasses and gloves to protect your hands and eyes. If using heat lamps to dry molds/parts, the lamps will be hot so caution should be used when around them.

Instructions:

1. Weigh your mold and record it's weight: _____
2. Pour the pre-made porcelain slip into the cavity (careful not to overflow).Observe the edge of the slip near the mold walls – you should be able to watch the material solidifying from the edges inward.
3. Your teacher will instruct you on how long to leave the slip in the mold. Once desired part thickness is reached, carefully pour out excess slip into waste container.
4. The casted part should now resemble the cavity in the mold.
5. Carefully weigh the mold and casted part and record: _____
6. Place the mold (with the slip casted part still in the cavity) under a heat lamp or in a sunny window for 30-60 minutes to dry the part.
7. Remove the part from the mold (this can be done carefully to save the mold, or the mold can be broken to remove the part easier).
8. Carefully weigh the part and record: _____
9. Let piece sit overnight to ensure that it dries.
10. Now you have a slip casted part!
11. Answer the questions in the Student Question Handout.

Clean up: Clean any spills you may have had of the slip, and throw away disposable cups used to hold the slip.

STUDENT QUESTION HANDOUT

Ceramic Processing: Slip Casting

1. What did you notice about the slip before and after you poured it into the mold? How did it change?

2. Calculate the difference in weight of the mold from before and after slip casting.

3. Why do you think the mold weight changed before and after slip casting? Describe what happened? If you left the slip in the mold for another hour, would the mold weigh more or less after?

4. Do you think the mold you used could be used again? Explain your answer.

The American Ceramic Society Materials Science Lessons

Warranty Disclaimer, Limitation of Liability and Safety Disclaimer

NO WARRANTY – DISCLAIMER OF WARRANTY

THE AMERICAN CERAMIC SOCIETY (ACerS), OFFERS THE MATERIALS SCIENCE KITS "AS-IS", WITH NO WARRANTIES WHATSOEVER, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY, SAFETY, FITNESS FOR ANY PARTICULAR PURPOSE OR NON-INFRINGEMENT OF PATENTS, COPYRIGHTS OR OTHER PROPRIETARY RIGHTS OF OTHERS. SOME STATES AND JURISDICTIONS DO NOT ALLOW LIMITATIONS ON IMPLIED WARRANTIES, SO THE ABOVE LIMITATIONS MAY NOT APPLY TO CUSTOMER. WHEN THE IMPLIED WARRANTIES ARE NOT ALLOWED TO BE EXCLUDED IN THEIR ENTIRETY, THEY WILL BE LIMITED TO THE SHORTEST DURATION PERMITTED UNDER APPLICABLE LAW. CUSTOMER MAY ALSO HAVE OTHER RIGHTS WHICH VARY FROM STATE TO STATE.

WITHOUT LIMITING THE GENERALITY OF THE FOREGOING, ACerS DOES NOT WARRANT THAT EACH MATERIALS SCIENCE KIT IS COMPLETELY ERROR FREE, WILL OPERATE WITHOUT INTERRUPTION, OR IS COMPATIBLE WITH ALL EQUIPMENT AND SOFTWARE CONFIGURATIONS. CUSTOMER EXPRESSLY ASSUMES ALL RISK FOR USE OF THE MATERIALS SCIENCE KITS.

LIMITATION OF LIABILITY

TO THE MAXIMUM EXTENT PERMITTED BY LAW, ACerS WILL NOT HAVE ANY LIABILITY OR RESPONSIBILITY TO CUSTOMER FOR DAMAGES OF ANY KIND, INCLUDING SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES (INCLUDING, WITHOUT LIMITATION, DAMAGES FOR LOSS OF DATA), ARISING OUT OF OR RESULTING FROM THE MATERIALS SCIENCE KITS, ANY COMPONENT, DOCUMENTATION, SERVICES OR MATERIALS MADE AVAILABLE TO CUSTOMER IN CONNECTION WITH THE MATERIALS SCIENCE KITS OR THE USE OR MODIFICATION OF ANY OF THEM, EVEN IF ACerS HAS BEEN ADVISED OF THE POSSIBILITY OF THE DAMAGES. IN ANY CASE, ACerS' AND ITS LICENSORS' ENTIRE LIABILITY UNDER ANY PROVISION OF THIS AGREEMENT WILL BE LIMITED TO THE AMOUNT ACTUALLY PAID BY CUSTOMER TO ACerS FOR THE PRODUCT OR TEN DOLLARS ($10.00), WHICHEVER IS GREATER. Some states do not allow the limitation or exclusion of liability for incidental or consequential damages, or have legislation which restricts the limitation or exclusion of liability, so the above limitation may not apply to Customer.

CALIFORNIA RESIDENTS

California Residents: I understand that I am waiving rights with respect to claims that are at this time unknown or unsuspected, and in accordance with such waiver, I acknowledge that I have read and understand, and I hereby expressly waive, the benefits of section 1542 of the civil code of California, and any similar law of any state, country or territory, which provides as follows: "A general release does not extend to claims which the creditor does not know or suspect to exist in his or her favor at the time of executing the release, which if known by him or her must have materially affected his or her settlement with the debtor."

MATERIALS SCIENCE SAFETY DISCLAIMER

The materials science kits contain lessons that are believed to be reliable regarding the safe use and handling of these materials in laboratories and student classrooms. ACerS, however, does not represent or warrant in this, or in any other publication, to specify minimum safety or legal standards or to address all of the compliance requirements, risks, or safety problems associated with the handling of hazardous materials, their use, or the methods prescribed for using them in laboratories or classrooms. This information is intended to serve only as a beginning point for information and should not be construed as containing all the necessary compliance, safety, or warning information, nor should it be construed as representing the policy of ACerS. The kits should be used by minors (under 18) only with adult supervision.

Without limiting the generality of the foregoing disclaimers, no warranty, guarantee, or other form of representation is made by ACerS as to the accuracy or sufficiency of the information and guidelines included with the materials science kits, and ACerS assumes no liability or responsibility concerning the use of such instructions and guidelines for any purpose. It is the responsibility of the users of these materials to consult and comply with pertinent local, state, and federal laws, regulations, and standards with respect to the handling of materials. Users of the materials science kits should consult with the school's legal counsel or other professional advisers about the applicable laws, safety issues, and compliance issues for the storage of materials and the methods for using the materials in school classrooms and laboratories.

THIS DISCLAIMER APPLIES TO ANY LIABILITY THAT IS, OR MAY BE INCURRED BY, OR ON BEHALF OF THE INSTITUTIONS THAT USE THE MATERIALS SCIENCE KITS; INCLUIDNG, WITHOUT LIMITATION, THE FACULTIES, STUDENTS, OR PROSPECTIVE STUDENTS OF THOSE INSTITUTIONS; AND ANY MEMBER OF THE PUBLIC AT LARGE; AND INCLUDES, BUT IS NOT LIMITED TO, A FULL DISCLAIMER OF ANY LIABILITY THAT MAY BE INCURRED WITH RESPECT TO POSSIBLE INADEQUATE SAFETY PROCEDURES TAKEN BY ANY USER.