Student sheet

In this practical I will be:

- Gaining an appreciation of how using a mixture of different sized mineral and rocks with a binder increases the difficulty of separation and increases the stability and strength of a composite substance such as mortar and concrete.
- Testing to see how varying the proportions of cement, water and different aggregates affect the properties of my concrete.
- Using my scientific knowledge and understanding to explain my results.
- Theorising what is happening chemically as the concrete sets.

Introduction:

You are a budding, young science-artist who has been apprenticed to the civil engineer Vitruvius (c.80-70 BCE – c.15 BCE). Vitruvius is researching how altering the ratio of cement, water and different aggregates affects the properties of concrete and he asks you to carry out some of the investigations. What's more he plans to include your results in his 'ten books on Architecture'!

Vitruvius has already found some interesting results, and like all good science-artists, you decide to investigate further…

Equipment:

Access to:

- 3 separating sieves with different sized holes
- Concrete mix in a 250 cm^3 beaker
- A small bag of mortar mix
- A small bag of cement   Irritant
- Mouth dust protection
- Transparent ruler
- Beaker (250 cm^3)
- Water
- Stop watch
- Top pan balance
- Overhead projector
- Tray or tub to sieve over
- Beaker of water (for the dirty spoon)

Method:

This activity will lead you to a working definition of concrete.

Not only will you separate out the ingredients that go into making concrete, but you will learn the important lesson of the time and energy needed to separate the largest sized stones from the smallest particles that contain the cement.

You should wear the mouth dust protector.

1. Place the sieves on an overhead projector next to a transparent ruler so you can estimate the size of the mesh holes in each sieve.
2. Collect a 250 cm^3 beaker filled with dry concrete mix.
3. Set up the sieves over another 250 cm^3 beaker, so that the one with the largest sized openings is at the top, the next smallest below it and the smallest below that.
4. Start a stop clock and using short brisk motions of the sieves, time approximately how long it takes for each sized particle to be separated.
5. The percent of each sized particle can be found by weighing each and comparing that to the total weight of the sample in the 250 cm^3 beaker.
6. Identify each group of particles from the sieve.

   - The finest particles contain the cement that makes up the bonding material holding the larger particles together when all of the four sized materials are mixed together with water.
   - The next group of particles in the succeeding sieves are the various sized stones that make up the aggregates of the concrete mixture.

An alternative approach to using the sieves to identify the components of concrete is to pour out some of the concrete mixture on a sheet of graph paper and, using the squares on the paper describe the range of the sizes of the particles that go into making concrete.

7. Mix each of the four different sized particles with a small amount of water to see which of the particles actually set.
8. If you are using the sieves, the source of each of the particle can be identified.
   - The small rocks that make up the largest particles and the next larger particles are called aggregate and can be mined from a gravel pit.
   - The third set makes up the smallest sand grains and large cement particles.
   - The fourth contains much of the cement that is ground to a very fine powder from clinker.

Going further:

Equipment

- Eye protection
- Cardboard mould
- Plastic glove
- Yoghurt pot and teaspoon
- Newspaper
- Water, sand, cement (Irritant), fine gravel

Method:

You must wear eye protection and a plastic glove.
Cover your bench with newspaper, and then collect all your other apparatus. Cement is an alkali, which can cause skin burns. Take great care when mixing it to avoid producing dust.

1. Put on your gloves. Take your yoghurt pot to the front bench to collect the ingredients. Using the teaspoons in each container, put 3 level teaspoons of cement, 3 level teaspoons of sand, and 3 level teaspoons of fine gravel into the yoghurt pot. Return to your bench. An alternative is to do all the mixing in a plastic, ziplock bag. (With the cement pre-weighed by the teacher). That way it is much less likely to be exposed to skin, or eyes.

2. Using your teaspoon, stir carefully to mix the cement, sand and gravel together. Add a little water, and carefully stir the mixture. **Remember you can always add a little more water, but you can't take it out!**
   When the mixture is right, your teaspoon should push easily into the mixture, leaving a hole when it is taken out.

3. Scrape the mixture into a mould (10cm x 1cm x 1cm). Mark the mould, record mixture composition, so that you will know that it is yours, and it will indicate what the mixture is.

4. If you have time, make at least one other bar of concrete. You must use 9 level teaspoons of material in total, but you should vary the proportions of the mixtures, e.g. 4 of cement, 3 of sand, 2 of gravel, and so on. Label the bars carefully, and record exactly what you have put into each.

5. **Do not wash any concrete down the sink**. Put the yoghurt pots (and any waste mixture) in the bin provided. Put your teaspoon in the container of cold water provided. Pull your glove off inside out, and put that in the bin with the used yoghurt pots.

6. Tidy your bench, and then wash your hands. Remove your eye protection when told to.

Now let's see how proportioning changes the mixtures properties.

Start by adding 3 to 5 times more water than required to cement and concrete mixes.

Now test two mixes: water mixed with concrete mix (cement, small and large aggregate), water, and water mixed with mortar (cement and small aggregate).

This will demonstrate how many sizes of particles are needed in a concrete mix. Now try the following mixes and comment on the way the properties change with each mixture.

1. Place one part concrete mix to five parts water a jar. Shake the mixture and let it set for an hour or overnight.

2. Remove larger sized aggregate from a dry concrete mix (or use a mortar mix), pour one part of the finer mixture into a jar, and add five parts water.

3. Shake the contents and let it settle for an hour or overnight.

4. Measure each layer to calculate the percentage of aggregate of each size in both mixes.

5. Compare the two mixes to understand that different particle sizes play a role in quality concrete and see the difference between concrete and mortar.

Two different sized aggregates can be used to show that the total volume of space between aggregates does not change when the size of the aggregate changes.

6. Measure the amount of water that it takes to fill two 1000 ml beakers, each containing a different size of aggregate.

7. The volume of space between particles lessens only when the different sized aggregates are mixed. This can be shown rather dramatically if two different sizes of plastic beads are used.

8. Review your experience with the aggregates from the mortar mix. The aggregates are of such a size to allow the most efficient surface contact between the cement paste and the different sizes of aggregates.

The amount of cement paste used must be at minimum equal to the spaces in between the aggregate particles and a small amount more to make the concrete mixture relatively easy to move while pouring concrete and making the surface smooth. This is known as “workability.”

1. Using polystyrene cups, weigh out 500 grams of mortar mix (sand and cement mixture), add 75 grams of water.

2. Mix until the lumps disappear from the mortar mix.

3. Weigh again to find the total weight and the added amount of water as a check.

4. Set the cup with the concrete mixture aside as well as another polystyrene cup of water filled to about the same level as the cup with the concrete. Weigh the cup of water.

5. Set the cup of water next to the cup of concrete. This cup of water is used to indicate how much water evaporates from the surface of the concrete before complete hardening occurs.

6. Wait about 24 hours and weigh each cup again.

The concrete will have lost only a fraction of the water to evaporation from the exposed surface.

You can compare the loss of water from the concrete with that of the cup of plain water that also lost some water due to evaporation. Both of these amounts of water are small when compared to the original amount of water added to the concrete that does not evaporate to make the hardened concrete. By comparing the amounts of original ingredients to the weight of the final concrete it is clear that the concrete does not dry out.

The concrete mixture may lose a little more water than the cup with the water only. If you look carefully you’ll see that the concrete’s surface is not smooth. This rougher surface area makes it possible for water to evaporate faster than the water in the cup alone. Again, this amount of water is negligible when compared to the water added into the concrete mixture that went into the chemical reaction to make the hardened material.

Discuss what efforts workers in the construction industry might take to eliminate evaporation from the surface of newly poured concrete.

Theory:
The Greeks discovered the power of a volcanic rock known as the **Pozzolanas** which included Santorin earth. This had been used in the Eastern Mediterranean since 500–400

BCE. The Romans eventually fully developed the potential of **lime-pozzolana paste** when they used pozzolana as a binder in Roman concrete for buildings and underwater construction. Roman concrete was also used to make roads. The word concrete comes from the Latin word "*concretus*" (meaning compact or condensed).

Roman concrete, known as **opus caementicium**, was used in construction during the late Roman Republic and through the whole history of the Roman Empire. It **was hydraulic-setting** (water-setting) cement with many material qualities similar to modern **Portland cement**.

Roman concrete was used frequently with a brick-facing. The concrete varied in its **aggregate** and this allowed different arrangements of materials leading to the Concrete Revolution, in which structurally complicated forms, such as the **Pantheon dome** were constructed.

The mineral **Pozzolana**, also known as **pozzolanic ash** (Latin: *pulvis puteolanus*), is a **siliceous** and **aluminous** material. When mixed with water at room temperature and **calcium hydroxide** it reacts to form **insoluble calcium silicate hydrate** and **calcium aluminate hydrate** compounds. These compounds are the materials possessing cementation properties and bind the aggregates together.

Pozzolana is derived from one of the primary deposits of **volcanic ash** used by the Romans at Pozzuoli near Naples. We still use the name pozzolana but it is applied to any volcanic material (pumice or volcanic ash), composed of fine **volcanic glass**.

The Roman civil engineer **Vitruvius** (c.80–70BCE - c.15 BCE) speaks of four types of pozzolana: black, white, grey, and red, all of which can be found in the volcanic areas of Italy, such as Naples. Vitruvius, writing around 25 BC in his *Ten Books on Architecture*, distinguished types of aggregate appropriate for the preparation of lime mortars. For structural mortars, he recommended *pozzolana*, brownish-yellow-gray in colour near Naples and reddish-brown at Rome.

Vitruvius specifies a ratio of 1 part lime to 3 parts pozzolana for cements used in buildings and a 1:2 ratio of lime to pozzolana for underwater work, essentially the same ratio mixed today for concrete used at sea.

The recipe for Roman Concrete was lost between 500CE and the 1300s. Then between the 1300s and the mid-1700s, the use of cement gradually returned. The *Canal du Midi* was built using concrete in 1670, and there are concrete structures in Finland that date from the 16th century.

Portland cement is a generic term for nearly all modern cement. It owes its name and origin to Aspdin (a British stone mason) who in the 1820s, searched for an equivalent to the Roman cement (derived from volcanic ash and other naturally occurring minerals).

Aspdin's name for his invention served two purposes. It distinguished the material from Roman cement. Concrete made from his new cement resembled the stone quarried on the Isle of Portland so making marketing easier.

Modern Portland cement is the product of high temperature conversion of finely ground materials often basic blends of limestone (calcium carbonate $CaCO_3$), clay, and shale. The product of the heating is a mixture containing the four key ingredients for cement: calcium oxide (CaO), silica (silicon dioxide SiO_2), alumina (aluminium oxide Al_2O_3), and iron (Fe).

Because producers rely on materials from the surroundings, cement plants are often sited close to quarries with rocks bearing some or all of these minerals.
When processed in a long horizontal furnace known as a rotary kiln, blends of these raw materials undergo chemical changes to form a glass-like material called clinker. The clinkers mixed with gypsum (calcium sulfate CaSO4) are ground to a fine powder and the result is cement powder.

Addition of water to this cement mixed with sand, gravel or crushed stone, (known as fine and coarse aggregate) activates the chemistry of cement. The water hydrates the cement's calcium compounds to form new compounds that bind the aggregates into concrete.

The original dicalcium silicate hydrates, which form more slowly, contribute to the strength of concrete at later stages. The following word equations describe the production of concrete.

Tricalcium silicate + Water

Calcium silicate hydrate + Calcium hydroxide + heat

Dicalcium silicate + Water

Calcium silicate hydrate + Calcium hydroxide + heat

Of the chemical reactions important for providing the strength for concrete the above reactions are the most important.

The two calcium silicates, which constitute about 75 percent of the weight of Portland cement, react with water to form two new compounds: calcium hydroxide and calcium silicate hydrate. The latter is by far the most important cementing component in concrete.

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The engineering properties of concrete—setting and hardening, strength and dimensional stability—depend primarily on calcium silicate hydrate gel. It is the heart of concrete.

When concrete sets, its gross volume remains almost unchanged, but hardened concrete contains pores filled with water and air that have no strength. The strength is in the solid part of the paste, mostly in the calcium silicate hydrate and crystalline phases.

The less porous the cement paste, the stronger the concrete. When mixing concrete, therefore, use no more water than is necessary to make the concrete plastic and workable. Even then, the water used is far more than is required for complete hydration of the cement. The water-cement ratio (by weight) of completely hydrated cement is about 0.22 to 0.25, excluding evaporable water.