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Research Experience for Teachers
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Bringing Materials Science Research into the Middle School Classroom

This is my fourth summer working with Materials Science research (three at Cornell, one at IBM Almaden in San Jose, CA). As a middle school teacher, I have been working to develop parallel tasks that will help my students wrestle with some of the same issues that materials scientists do, while still working at an appropriate developmental level. In essence, I teach these lessons by analogy.

Middle school students require formal teaching in meeting long term objectives by goal setting and the formation/completion of a sequential set of logical steps. They must also be taught to work in teams. Teachers strive to develop lessons that are open-ended enough to allow all ability levels to excel, and yet well-defined enough to focus on a small set of endpoints. The Parallel Task is one way to do this.

Parallel tasks begin with a complicated problem (such as those being researched in the materials science labs). For the middle school, a similar but simpler problem is defined—hopefully one that requires the students to face the same issues as the ones faced in the more complicated version. While the teacher may speak with the class about the complicated problem (to set the scene and the reason for the task), the students will actually only work within the parameters of the simpler lesson. Middle level research indicates that lessons based on real-life issues are far more effective than those "drill and kill" lessons that focus only on skill building, without a context.

In light of recent departmental work on gap analysis in math, it is apparent that we need to develop a local curriculum that is less driven by a textbook and more aligned with meeting the specific needs of South Seneca students. Student performance is known to be low in the areas of problem solving and communication, and many of our students have difficulty applying math knowledge to a variety of written problems. This project is part of an attempt to help address these gaps.

One advantage found at the middle level at South Seneca is that one or two teachers oversee all the students in grades 7 (and beginning next year, 6) through 8. It will only take the coordination of effort for these two people to have a significant effect on consistency across the middle grades. By adopting a single approach to teaching problem solving and communication, the hope is that students will experience measurable progress in the long term.

At South Seneca, we work with a population of students predominantly from a rural poverty demographic, with a higher-than-average percentage of special education classified students. This brings with it a challenge to our teaching staff: we MUST design lessons that will address the needs of a wide range of academic ability levels, physical and emotional developmental levels, and a spectrum of learning and emotional disabilities. If we try to teach by the one-size-fits-all approach, we fail.

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In addition to these hurdles, we are also faced with barriers in literacy and numeracy, and the ability to apply learned knowledge to a flexible problem-solving situation. Often our students can learn “the basics” without being able to apply them meaningfully.

In many ways, learning mathematics is analogous to learning a foreign language. There is new vocabulary to master, rules of “grammar,” and the construction of meaning as we apply all these elements to real situations. Students must have the depth and flexibility to do application. Our work on gap analysis seems to suggest that our students have a sufficient grasp on background mathematical knowledge (including the ability to do computation), but that they struggle with constructing it in a useful way. This information should change our approach in the classroom.

Using the New York State intermediate math standards as a guide, I have identified sixteen subcategories of math topics that students must master in time to take the state assessment in May of their 8^{th} grade year. Many of the categories can be addressed using scenarios analogous (or directly applicable) to procedures carried out in Materials Science laboratories. These categories are:

Fractions—adding/subtracting, multiplying/dividing, putting rational numbers in order from least to greatest, converting any fraction to a decimal and a percent, finding any fraction of any number, using simple fractions (one-half, two-thirds, etc.) as a framework for estimation

Percents—finding any percent of any number, calculating the percent change from one number to another, using simple percents (50, 100, 200) as a framework for estimation

Working with Numbers—recognizing rational/irrational/real numbers, classifying integers, converting between standard and scientific notation, writing and solving proportions, using rates

Operations—creating lists of factors and multiples of a number, using divisibility rules, finding prime factors, generating a list of perfect squares, finding the additive and multiplicative inverse of a number, working with exponents, finding/estimating square roots, using order of operations to evaluate mathematical expressions, adding and subtracting signed numbers, evaluating absolute value expressions

Number Properties—recognizing and using the Commutative, Associative, Distributive, and Identity Properties of numbers

Probability—finding the probability of a single event, using a tree diagram to list a sample space, finding the probability of compound events, recognizing when permutations and combinations are appropriate, calculating permutations and combinations

Measurement—using a ruler and protractor accurately, converting from one standard unit to another, finding accurate measurements using a scale drawing

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Lines/Angles—recognizing acute/right/obtuse angles, working with complementary and supplementary angles, recognizing and evaluating vertical angles, comparing/contrasting similar and congruent figures, identifying corresponding sides and angles in similar/congruent figures, finding relationships among angles in a parallel lines/transversal diagram, calculating area and perimeter of figures, identifying and working with regular polygons

Circles—identifying parts of a circle, calculating area of a circle, calculating circumference of a circle

Quadrilaterals—identifying and comparing/contrasting the trapezoid, parallelogram, rectangle, square, and rhombus; calculating the area of each of the special quadrilaterals

Statistics—using a list of numbers (data) to analyze central tendency (mean/median/mode), using a frequency table, creating/analyzing a variety of data graphs (bar/line/circle/box-and-whisker)

Algebra/Trigonometry—writing a variable expression, moving numbers and variables within an equation, solving an equation, recognizing and extending a pattern, using the sine, cosine, and tangent ratios to analyze a right triangle

Common Formulas—calculating simple interest, finding the surface area of a three-dimensional figure, calculating the volume of a box, solving for one unknown in a given formula

Triangles—analyzing an isosceles triangle, finding the area of a triangle, proving two triangles congruent, analyzing right triangles using both the Pythagorean Theorem and the trigonometric ratios

Graphing—identifying the four quadrants on the coordinate plane, plotting any point on the coordinate plane, finding the distance between any two points, graphing linear equations, filling out a function table, graphing lines in the form y=mx + b, graphing inequalities on a number line

Transformations—recognizing and performing a reflection, a dilation, a translation, and a rotation on a figure, recognizing both line and rotational symmetry

It is imperative to recognize that these topics are ***the raw materials with which students are expected to use to solve problems***; they are not endpoints on their own. While it is necessary for students to master these topics, mastery is not sufficient when students are assessed on state standards. They must be able to apply these skills to construct solutions to a wide variety of problem situations.

This requirement for application of math knowledge becomes a problem for students who are exposed only to the typical textbook approach in the classroom. Inevitably under this approach, topics are taught sequentially leading up to the end of the school year, with the final chapter of the book taught and practiced for the first time only days before the final

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exam. Except for a short period of "review" set aside between the last chapter and the exam, students never get much of an opportunity to use the entire "set of tools" available to them for solving problems.

Using lessons such as the ones outlined below, I propose to challenge students to use their raw materials to solve open-ended, materials science based problem situations.

Lesson One: Thought Experiments to Appreciate the Nanoscale

Summary: Students will imagine objects that are a millimeter in size, each one packed with a thousand "somethings," and the somethings themselves are partitioned into a thousand units. The goal is an appreciation for the size of a nanometer. Intended for middle school grades (6-8).

Skills/Concepts: measurement, number sense

Equipment: meter sticks with millimeters, paper, pencils

Estimated time for lesson: 15-30 minutes (best delivered in small groups)

Lesson Plan: Teacher will introduce the lesson by asking students to consider the numbers one million, one billion, and one trillion. Together, the teacher and students explore the magnitudes and relationships among these numbers. Do the numbers seem significantly different to students? Do they seem about the same (essentially, a "big amount")? By extension, the teacher asks the students to consider the scale on a meter stick, from meters to centimeters to millimeters. Students should be able to see the size of a millimeter. Now the teacher asks students to imagine a truck the size of a millimeter. The students might even attempt to draw a truck that small. Further, imagine a whole line of trucks in a big traffic jam along the meter stick. How many trucks can fit on the meter stick? Tell the students that in each truck are a thousand pieces of plywood stacked end to end. Can they imagine how thin those pieces of plywood must be? If each one is a thousandth of a millimeter, then they measure one MICRON across. What if each piece of plywood had a thousand grain lines on its width? Can we even imagine how small those lines must be? If each is a thousandth of a micron, they would measure a NANOMETER across. When materials scientists work with measurements, they often are measuring their products in nanometers. Help students appreciate how small this measurement is, and ask them to try to remember this scale.

As a follow-up, students might be asked to come up with a different analogy along the millimeter-micron-nanometer scale—something other than trucks and plywood.

Possible assessments: oral or written questions concerning metric scale from meters to nanometers (lesson is not necessarily intended for this purpose however)

Other possible resources: conversion charts, micrographic drawings or photographs on the nanoscale, microscopes with micrometers available, articles containing references to nanoscale measurements

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Possible enrichment: activities using any of the resources listed above

Lesson Two: Phase Diagram

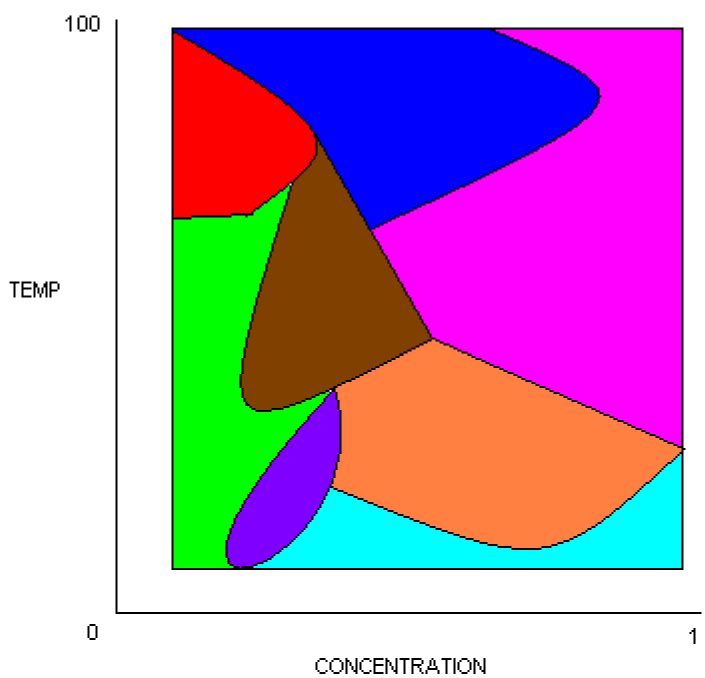
Summary: Students will work with a simplified "phase diagram" in order to appreciate how such a diagram is used to determine preparation variables. The diagram students will use contains only one variable on each axis, compared to the two variables embedded on the y-axis of the diagram used in the self-assembly project I worked on this summer. Intended for middle school grades (6-8).

Skills/Concepts: Plotting points, graphing, functions, ratios, fractions, measurement

Equipment: pre-drawn phase diagram on graph paper, pencils, paper

Estimated time for lesson: 30 minutes

Lesson Plan: Teacher will talk to the class about the use of a phase diagram in the lab setting. In simple terms, students will explore the need to manipulate preparation variables in order to achieve desired results (in this case, a specific morphology of the end product). Teacher hands out new phase diagram (color coded), and helps students discover a range of values for each axis which would achieve a product in the "green zone," or any of the other "phases." Next, the teacher provides students with sample preparation directions, and asks students to predict which phase or zone would describe the product. The diagram might look something like this:



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Assessment: later appearances of phase diagrams on tests/quizzes, application of phase diagrams in laboratory settings

Other possible resources: articles with other versions of phase diagrams in them, various graphs and charts for interpretation

Modifications: Some students might only be asked to identify points on the diagram while others will be asked to do more interpretation. Enrichment activities might include the calculations necessary to produce a sample with differing concentration amounts.

Contributors: South Seneca Middle School, Tom Phillips, Phong Du, Uli Weisner

Lesson Three: The Recipe

Summary: Students will use the analogy of a cup of coffee to explore the manipulation of variables (both in materials and in processing) necessary to achieve a set of desired properties in materials science. Intended for middle level grades (6-8).

Skills/Concepts: measurement, fractions, ratios, lab safety

Materials: everything needed to make coffee (cups, stirrers, coffee maker, coffee grounds, instant coffee, spoons, sugar, cream, water, napkins)

Estimated time of lesson: 60 minutes

Lesson Plan: Teacher will lead discussion with students on the concept of sample preparation. What are the variables involved? What are the choices facing a scientist as she prepares a sample for use in an experiment? What guides her decision making? How must she include a vision for her desired product as she prepares the sample?

After the discussion, students and the teacher will move to a cafeteria setting where all the materials for making coffee are available. The discussion is repeated, using "coffee" as a replacement for "sample." Variables? End product? Choices? Vision?

For the remainder of the period, students and the teacher will experiment with the manipulation of variables in the quest for the "perfect" cup of coffee. After clean-up, the class may also revisit the lesson, developing the analogy and even considering the difference between materials-based variables and process-based variables.

Assessment: reflective journal (What are the parallels between making coffee and preparing a materials science sample?)

Other possible resources: articles detailing sample preparation, more equipment/methods for making coffee

Modifications: For less advanced students, the lesson could omit the details about sample preparation and simplify the focus (How can we arrive at the perfect cup of coffee?). For

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more advanced students, the analogy can be further developed and explored. What are materials-based variables? What are process-based variables? How do they interact?

Contributors: South Seneca Middle School, Uli Weisner

Lesson Four: The Golden Ratio and the Perfect Face

Summary: Students will experience first hand the process of evaluating an image quantitatively (as opposed to "by eye"). The concept of the "Golden Ratio" is one that comes up often in discussion of math in nature, and the Greeks used it to define the features of a pleasant-looking face. In materials science, it is necessary to judge the quality of an image quantitatively, and using the Golden Ratio, middle school students can judge the "quality" of a person's photograph. Intended for middle level grades (6-8).

Skills/Concepts: measurement, ratios, comparing and contrasting, data analysis

Materials: photographs of famous people, rulers, pencil, paper, instructions for activity

Estimated time of lesson: 45-60 minutes

Lesson Plan: Teacher introduces the lesson by explaining the problem of judging the quality of AFM images. Discussion should focus on the difference between a subjective opinion about an image and a quantitative analysis, and the problems of *designing* a method for doing a quantitative analysis. Next, the teacher will review with the students their knowledge of the Golden Ratio, and the possibility of using it to compare a photograph of a face with the ancient Greeks' idea of perfection. Teams of students will take two photographs (one of a famous person known for good looks, and one of a famous person known for being not-so-good looking) and measure their features to compare them with the Golden Ratio. At the conclusion of the activity, the class will reconvene to discuss the success or failure of the method as a means for evaluating photographs.

Assessment: evaluation of the technique/accuracy of each group's measurements

Other possible resources: a bank of photographs of famous people, other examples of quantitatively analyzing images

Modifications: Less advanced students might benefit from a simpler example of analyzing images quantitatively (this could be easily designed by the teacher). More advanced students could design their own methods for quantitatively analyzing images, and they could even explore some of the complicated ways that AFM images are analyzed. (See brief description of lesson five)

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Lesson Five: Voronoi Polygons

Summary: This lesson is not fully developed as of yet. The idea is to help students derive the same Voronoi polygons that the computer finds when analyzing a typical AFM image. The math involved can be explained in fairly general terms, or it can be quite complicated, depending on the depth with which the teacher chooses for the students. There is the possibility of using actual images, or a pre-drawn grid of dots (either regularly or irregularly shaped). Before fully writing this lesson, I'd like to explore these possibilities further.

Contributors: Uli Weisner and Phong Du

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