Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
2001 Volume II: Art as Evidence: The Interpretation of Objects

An Approach to Chemistry via the Analysis of Art Objects: The Scientific Method, Laboratory Safety, Light and Color Theory

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by Patricia A. Morrison

Purpose of Unit:

Too often in today's public school education learning and teaching are compartmentalized so that students never fully appreciate the inter-relatedness of all disciplines. When I accepted a chemistry position at Cooperative Arts and Humanities Magnet High School, I realized that, by its very nature, the school would not attract students with the strongest math and science interests, but I was excited by the mandate to introduce the arts into academic subjects. Here was an opportunity to highlight the connections between all subjects. I planned projects with visual arts, dance, theater and music teachers, but as rewarding as these enrichment activities were, they were not the truly integrated approach I was seeking. Dr. Jules Prown's seminar, "Art as Evidence," provides an opportunity to develop a unit which employs art as the key to open the door to chemistry, the scientific method, and color theory as it relates to light, pigments, and ionic compounds. This unit will develop a series of lessons revolving around a detailed examination of Joseph Wright's "The Blacksmith Shop." The approach will be used with lessons throughout the year and culminate with a visit to the art conservation laboratory at the Yale University Art Gallery.

I have always believed that the artist and scientist have much in common; Dr. Prown's method of object analysis provides an ideal means of highlighting these similarities. This method requires keen observational skills and a disciplined, orderly approach for proceeding from the general to the specific, the obvious to the more subtle.

The systematic analysis proceeds in three distinct stages: description, deduction and speculation.

The first stage reaches for objectivity by describing exactly what one sees without drawing any conclusions. This description starts with substantial analysis which, in addition to including measurements of physical size and determining prime materials, may involve using the tools normally associated with the scientist: ultraviolet lamps, infrared photographs, electron microscopes and x-ray diffraction. (Prown, 7-8) Our spring visit to the conservation lab will give students an opportunity to see these tools employed.

Iconography, or analyzing the content of the picture, comes next, followed by a formal analysis of the object's visual character. The latter includes the way that lines, shapes, textures, color and light help to organize the picture both two-dimensionally and three dimensionally. (Prown, 8) Examining something "familiar," like a painting, in this detailed manner sharpens students' ability to describe what they actually see when a chemical reaction occurs.

The second stage in the method moves, ideally, from the complete detachment of the observer to his sensory, intellectual and emotional involvement with the object. In other words it is the time for posing questions: What is the setting or where is the action taking place? How, what, would you feel if you were present in the painting? What is happening just beyond the frame? What is the purpose of the object? "Deduction must be something that reasonable people agree on, or be set aside." (Dr. Jules Prown, March 20, 2001) Just as one deduces information not specifically illustrated in a painting, students must deduce possible causes of the observations they make. Some deductions are obvious; others require further questions, research, and experimentation.

The final stage in the analysis process, speculation, activates the imagination and calls for creative interpretation and development of hypotheses and theories concerning all the data one has collected. Steeped in the first step of creative speculation, one then must move to a plan of scholarly research to substantiate possibilities that have been suggested. This is the same path that the scientist follows, only the scientist adds experimentation. (Prown, 9-10)

Because I normally have a high percentage of students with a visual arts focus, I plan to begin the year with an introduction to Dr. Prown's method of object analysis and a visit to the Yale Center for British Art to examine Joseph Wright's *The Blacksmith's Shop* . Wright painted this oil on canvas in 1771, the same period that chemistry was emerging out of alchemy. He is an ideal artist to study because he was among the first to "exploit" the "artistic possibilities" (Nicholson, Vol. I , 111) of this forward leap of science. Although not a scientist himself, his close friendships with many members of the Lunar Society, a group of intellectuals interested in the newest inventions and latest developments in science (Nicholson, 131) and with leading industrialist patrons, such as Josiah Wedgwood (Nicholson, 143-149 and Richard Arkwright (Nicholson, 162-169) kept him in close contact with the world of science and technology.

When painting a scene revolving around science, such as *The Alchemist in search of the Philosopher's Stone* , illustrating the discovery of phosphorus, (Nicholson, Vol. II, 74), *A Philosopher giving a Lecture on the Orrey* (Nicholson, 30-31), an 18th century version of a planetarium (Nicholson, Vol. I , 114), or *An Experiment on a Bird in an Air Pump* , (Nicholson, 35,36) he worked meticulously to assure the accuracy of both equipment and process (Nicholson Vol. I, 120). John Whitehurst, a clockmaker and Lunar Society member (Nicholson 114, 131) and Peter Perez Burdette, cartographer and specialist in aquatint techniques (Nicholson, 117-119) frequently acted as consultants for Wright's scientific pictures. These paintings intrigue the viewer by combining a clear presentation of factual knowledge and scientific apparatus with the magic and mystery of discovering the unknown. For Wright, like for most men of his age, class and upbringing, "The magic had not gone out of industry, and …it represented a hope for the future…. (Nicholson, 121) Although we will not have time to examine these paintings in chemistry, I will encourage my visual arts students who are interested in extra credit to research these works further.

On the opening day of school a copy of *The Blacksmith's Shop* , along with a series of former students' etchings which emphasize the chemistry-art relationship, will be displayed on the walls. These will provide the background for my explanation to the students of my approach to chemistry. The in-depth study of five major topics begins in *The Blacksmith's Shop* : the scientific method, laboratory safety, fundamental definitions and concepts in chemistry energy, chemical and physical changes, chemical and physical properties and the theories of light and color and their relationship to atomic structure. Because this is a very unusual approach to chemistry in a standard college course, especially in these days of extreme emphasis on CAPT scores and meeting standards, this unit shows how I incorporate the painting in an extended series of lessons and assignments rather than a detailed single lesson. A teacher using this approach might well integrate different laboratory experiments and teaching strategies. An annotated bibliography suggests enrichment material that a teacher using this integrated approach might want to investigate.

Introduction to Topics in Chemistry via Art

The objective of each lesson in this unit is to learn chemistry its methods, definitions and concepts by way of an in-depth analysis of *The Blacksmith's Shop* in order to emphasize the interrelatedness of science and the arts, to encourage accurate writing and creative thinking, and to discourage the compartmentalization of knowledge. The methods used will include class discussion combined with question and answer sessions, brainstorming, lectures, demonstrations, lab experiments, interdisciplinary activities with the visual arts department, videos, and trips to the Yale Center for British Art and the Yale University Art Gallery Conservation Laboratory.

Interdisciplinary activities with the visual arts department are always collaborative efforts based on a clearly designed criterion sheet with focused critical areas that will be graded. This allows all students, even those with minimum artistic ability, to be successful in completing a project designed to deepen both an understanding of chemistry and an appreciation of art. After I introduce the science related to a topic, such as the electromagnetic spectrum and color theory, the art teacher illustrates how these concepts relate to paintings and helps the students create an individual work of art. In the case of color theory, she will discuss and illustrate the color wheel and the three primary dimensions of color hue, value and saturation. Then she will teach students two simple brush strokes, enabling them to create a painting that clearly exemplifies the use of primary pigments to make secondary pigments and demonstrates the distinction between value and saturation. After explaining the affect of adjacent colors on each other, the art teacher will join the class to discuss Wright's use of color in *The Blacksmith's Shop* .

Topic One Observation as the Foundation of Science: An Introduction to the Scientific Method.

Opening Day Class will begin with a discussion of "What is science?" Writing main ideas on the board, we will develop a working definition of "science." This will be followed by a discussion of student and teacher expectations and an explanation of my approach to learning chemistry. This will be my opportunity to stress the importance of presence (the need to be in class) and the role of science as an integral part of everyday life that affects both the way we live and the various art disciplines each students has chosen by deciding to come to COOP.

Assignment: Write two well developed paragraphs describing or explaining the characteristics you think a person needs to be successful in your chosen art field (visual arts, theater, dance, writing, or music) and the characteristics you think are necessary to be a successful scientist. Remember that English usage counts. (All assignments are due the next day.)

Lesson One List characteristics students have selected in six categories on board. Bring out the importance of observation, with leading questions if necessary, for success in all six fields. ("Listening" in music equals "ear observations.")

Do a series of demonstrations using two sets of six prepared colorless solutions: hot water, dilute hydrochloric acid, dilute ammonium hydroxide, silver nitrate solution, sodium chloride solution, and phenolphthalein. To the seated students these solutions will all appear the same. Students will have a diagram showing the test tubes and their contents on which to take notes. Emphasize that students are to write down only what they actually see no deductions for each demonstration.

> a. Add three drops of phenolphthalein to all test tubes except ammonium hydroxide. add indicator to only one tube of ammonium hydroxide nothing happens except ammonium hydroxide turns pink.
> b. Add magnesium ribbon to one water and HCl and mossy zinc to second water and HCl bubbles and change of color seen in some test tubes.
> c. Add silver nitrate to sodium chloride solution turns cloudy
> d. Add NH_4OH to HCl till color turns pink. Reverse color by adding HCl

Write equations on board. Explain shorthand of equation and progression from observation (bubbles) to deduction (hydrogen gas). Note that phenolphthalein turns pink in the presence of hydroxide ions. (Students should have some familiarity with equations, but I am not "teaching" how to write equations at this point and do not expect my students to reproduce formula equations.) Prove the accuracy of the deduction that bubbles indicate the formation of hydrogen gas by testing for hydrogen gas. (A burning splint inserted in the mouth of the test tube "pops.")

Assignment: Read text, *Chemistry, Visualizing Matter* , pp. 2-6. Define acid, base, indicator, and chemical change, and give one example of each. (These, together with "science," will be the first entries in a running vocabulary list that students must keep in their chemistry notebooks. This list should include vocabulary stressed in class as well as bold-faced vocabulary defined in the margins of their textbook.

Lesson Two Restate fundamental importance of being a keen observer. Note that the cloudy test tube from yesterday's experiment has now cleared; a clear solution covers a solid precipitate which has settled to the bottom.

Introduce Dr. Prown's method of analytical analysis using a slide of Thomas Eakins' painting *John Biglin in a Single Scull* . (See introduction for a brief explanation of this method.)

Assignment: Read text pp. 16-20, "How do Scientists Approach Problems?"

Lesson Three Go to Yale Center for British Art to examine Joseph Wright's painting, *The Blacksmith's Shop* . The class will analyze the painting beginning with a general description and proceeding to more minute details, lines, shapes, color and texture. One student will volunteer (or be chosen) to record all class observations. Each student will be given a copy of the painting to keep in his/her notebook.

Assignment Divide class into six groups. The first group gives a general description of the painting, including setting details; the next three groups write a detailed description of the central group of blacksmiths, the group of three figures on right, or the group on left; the fifth group describes lines and shapes; the final group discusses color and textures. Each student in the group must write up his/her own detailed description (minimum one page). Be careful to include only observations, no deductions. Use present, active colorful verbs. (See concluding narrative for description of painting and details that student papers should include.)

Lesson Four Show slide of Wright's painting. One student from each group will read his/her paper, and the class will supplement the observations. If student's observation that the forge is located in a church raises the question of science and religion then we will discuss this topic. In my opinion, the relationship between science and religion always needs to be addressed. They are not in opposition; they ask and answer different questions. Science cannot tell one how to live life in relationship to others, and religion cannot tell you the structure of the atom. It is important for students to know their instructor's perspective; I believe that the more we learn from science, the more amazing we find creation. If the science-religion question does not arise out of the painting, the topic will not be discussed until it does arise or until we discuss the Big Bang Theory and the creation of the elements.

After explaining and emphasizing the differences between observation and deduction, referring back to chemical experiments, guide the class in drawing deductions from this scene. (See concluding narrative for deductions drawn from painting to see what should arise from this exercise.) Questions raised and answered should include queries like the following:

What work is being done? By whom? For whom?
What tools and materials are being used?
Where is work being done? Why?
What is the source of light?

Assignment List five other questions or ideas, suggested by the painting, that might require further research. Remember careful observations lead to deductions that lead to speculations that require investigation. Questions for further research might include:

> What causes light? What is light?
> How does the artist get different colors? What is paint?
> What causes color?
> How do you preserve old paintings?

Lesson Five Begin class without verbal comment with demonstration of twenty-four hour clock (symbols of the first twenty-four elements replace numbers) that runs on orange juice. Students will ask questions such as "How long will the clock run?" "Will it run on apple juice?" Point out that careful observation of something new always leads to questions, just as it did when observing the painting. Have class quickly generate more questions relating to the orange juice clock. (Class will not proceed until they have generated at least twenty questions.) The answer to each question is a variation of "Try it!" In other words, experiment!

Summarize the scientific method emphasizing that it is a process and not a lock-step order for proceeding in science: observe, question, research, hypothesize, experiment, analyze data, draw conclusion(s). Then repeat cycle; develop a new hypothesis either because the first hypothesis was incorrect or to strengthen and expand the original idea. Theories and laws may result from experiments; therefore, distinguish between theory, a broad explanation, and law, a statement, usually mathematical, of facts.

Assignment: Write a paper (minimum one page) comparing and contrasting the scientist's approach to solving a problem versus the art historian's approach to examining a painting. What theories might an art historian develop?

Topic II Laboratory Safety

Lesson Six List the various questions students raised in homework assignment day five. Add to list if needed; as a class, answer questions if painting provides an answer; indicate questions that will be answered later in year or suggest possibilities for further research.

Elicit basic difference between scientists' approach and artists' approach: experimentation. If you are going to carry out experiments you have to follow laboratory safety precautions. Brainstorm safety precautions with students. Have students locate safety equipment in lab such as fire extinguishers, shower, eyewash, and fire blanket. Pass out safety rules and discuss any rules that students omitted. Pass out "cartoon" of safety violations. Students need to list violations. Candy bar prize to student who finds the most violations.

Assignment: Read text pp.12-14. Pretend that you are a government inspector from OSHA. Write a citation for safety violations to the owner of the blacksmith's shop. Specifically list the following: 1) All violations; 2) All safety precautions that he needs to initiate; 3) All safety precautions that he is currently following and should continue to follow. (Note a citation is written in formal language ____(Name)____________ of _____(Establishment)_____ located in ____(Place)_________ is hereby notified that....)

Topic III Introduction to Chemistry; Review of Basic Concepts and Vocabulary

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Lesson Seven To illustrate types of chemical changes perform two simple demonstrations: burning magnesium ribbon and decomposing hydrogen peroxide using manganese dioxide as a catalyst (and detergent to enhance the visual appearance of bubbles). Write equations on board emphasizing that chemical changes produce new substances. Students will note the signs (what they actually observed) of a chemical change recalling previous experiments as well as those just witnessed: production of lots of heat and light energy, formation of bubbles, formation of a precipitate, and change in color of an indicator. Class will end with a brief lecture defining chemistry, matter, mass, substance, physical change and chemical change.

Assignment: Read text pp. 44-45, 234-237. Add vocabulary words to running list. Write a paragraph explaining how the painting exemplifies the definition of chemistry, physical change and chemical change. Note the words "reaction" and "change" are often used interchangeably. Be clear and specific. Remember English usage counts.

Lesson Eight Discuss students' examples of chemical and physical changes and how they thought the painting illustrated "chemistry." The primary forms of energy produced are heat and light. The major physical change occurs as the blacksmiths reshape pig iron into useful implements; the major chemical change involves burning. Students should deduce (or should have deduced) that the blacksmith is burning wood or perhaps coal, and that the bellows provides additional oxygen to make the fire burn hotter.

Introduce tomorrow's lab, which will focus on physical change. Mix different substances together in front of students at the beginning of class. Students will have to separate these substances. Substances that are merely physically mixed together can be physically separated based on their properties.

Assignment: Read text pp. 37-39, 46-50.

Lesson Nine Laboratory Experiment on Separating Mixtures

Reiterate that physical changes do not produce anything new and, therefore, often can be undone physically. Iron that is shaped into one form can be reshaped into another. Give groups of three students five samples of physical mixtures to separate. Equipment in the room includes test tubes, funnels, beakers, filter paper, magnets, centrifuge, hot plates, and condensation tubes. Students may request any additional equipment that is available. The mixtures include:

Sulfur and iron filings
Salt and water

Salt and sand
Red food coloring in water
Catsup in water

Assignment: Complete lab write-up using skeleton format handed out in class. Explain how you separated each mixture. If you did not have time to finish separating each mixture, which is quite likely, explain how you would separate it. Try to use the proper name for each separation procedure.

Lesson Ten Review lab with distillation apparatus assembled. On the board, list methods of separation: filtering, evaporating, distilling, using magnet, using centrifuge. (Students may add decanting and chromatography based on their reading.) Indicate the physical properties that made separation by this method possible. The properties of substances determine the methods used to separate them. Just as reactions can be physical or chemical, so can properties.

By drawing on students' prior knowledge and teacher additions, chart the physical properties, subdivided into qualitative and quantitative, and four major chemical properties: burns, supports combustion, reacts with an acid, doesn't react (inert).

Assignment: Select three substances present in *The Blacksmith*'s *Shop* and list their physical and chemical properties. (Possible substances include: iron, oxygen, water, carbon dioxide, nitrogen and carbon.) Which substances are visible in the painting? Which substances did you deduce were present? What properties can you deduce from the painting? Remember that in chemistry the word "substance" means an element or a compound. Review text pp. 37-39, 48-50 and make certain that your vocabulary list is up to date and that you know all meanings.

Lesson Eleven Quiz on vocabulary, concentrating on physical and chemical changes, physical and chemical properties and methods of separating mixtures.

Again write equations for chemical reactions students have observed. Classify reactions: synthesis, decomposition, single replacement, double placement, neutralization and combustion (deduced from painting). Emphasize identification of reactions by carefully noting if reactants and products are elements or compounds. At a simplistic level one can identify types of reactions by counting and recognizing capital letters, groups, water (H2O) and carbon dioxide (CO2).

Assignment: Study sheet identifying types of reactions. (This topic will be revisited when students study writing and balancing equations.)

Lesson Twelve Reinforce definition of "chemistry": the study of matter, its structure, composition and the energy changes it undergoes. Examine painting from energy perspective. List kinds of energy illustrated in painting: heat, light, potential, radiant, electromagnetic, gravitational, kinetic (implied), and chemical (implied). Add any other types of energy they can recall: nuclear, electrical. Discuss potential energy (stored energy or positional energy) and kinetic energy (energy due to motion, K.E. = ½ mv2) as general terms. Classify all energy into four categories: kinetic (heat, mechanical), gravitational potential, electromagnetic (electricity, magnetism, radiant, chemical, light,) and nuclear.

Assignment: Rd. Text pp. 40-43. Rd. handout: Richard Feynman's essay on energy.

Lesson Thirteen Answer any questions on energy readings. Emphasize energy as a form of matter and the Law of Conservation of mass-energy, E=mc2. Return to painting and look at transformations of energy taking place. Have students give specific examples:

chemical to heat
chemical to light
chemical to gravitational potential
gravitational potential to kinetic
kinetic to ?

When you hit an iron bar, where does the energy go?

Topics IV and V: Introduction to the Theory of Light and Color

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Give a brief lecture on electromagnetic energy. Light is only a tiny fraction of the electromagnetic spectrum, but since we have built in receptors for this part, it fascinates us. Color makes *The Blacksmith's Shop* far more dramatic than a black and white reproduction. The color of light depends simply on the predominant wavelength; the far more complicated color of an object depends on the light it reflects. When all colors of light are combined one gets white. When all colors of pigments are combined, one gets black; there is nothing left to reflect. Tomorrow we will do two simple experiments to illustrate this point.

Assignment: Read Physical Science text pp. 535-543.

Lesson Fourteen Lab: Radial Chromatography and Light through a Prism

To illustrate that white light and black pigment are both combinations of all colors, we will separate out the colors of both. Students can separate white light by passing normal light from the sun or electric classroom lighting through a prism while waiting for their chromatogram to develop. (We will use a variety of chandelier prisms.) Using chromatography we will separate black pigments. To make a radial chromatogram students will draw a quarter-sized circle in the center of a 5"diameter circular piece of filter paper with a small hole in the center. On the circle they will place six equally spaced dots from six different pens. The various brand pens all contain water-soluble black ink. They will then make a filter paper cone wick, using a third of a piece of filter paper, to set in a plastic cup with one half inch of water. The point of the wick rests in the hole of the filter paper, which is supported by the cup rim. Wait for the chromatogram to develop.

Assignment: Complete lab report according to standard format:

Purpose:

Equipment and supplies:

Method:

Data and observations: (A chromatogram is data and must be included in report. Write out observations carefully.)

Conclusion: (Must relate to purpose.) Explain (hypothesize) why your chromatogram looks like it does.

Lesson Fifteen Discuss lab. Chromatography is a race. At the beginning all components of the mixture are combined in a "stationary" phase (on the filter paper), but as time passes, those substances that have a greater affinity for the mobile phase (the solvent that passes through or over the initial phase) outdistance those substances which prefer the stationary phase. "Eventually all molecules will be separated into homogeneous groups (zones or bands)." (GHAMIS, Publication distributed at April 28th Workshop at SHU)

For further exploration there are two take-home challenges: "Chromatography on Paper," chromatograms of various colored markers using various solvents, and "Fabric Chromatography," emphasizing the difference between "bleeding" and chromatography. Other aspects of chromatography to research include: thin layer chromatography, high pressure liquid chromatography, gas chromatography, and forensic applications of chromatography. (SHU, April 28th Workshop)

Return to painting and introduce color theory with chart on board listing the six primary and secondary colors: magenta, red, yellow, green, cyan blue and dark blue. Emphasize that with the primary colors of pigments magenta, yellow and cyan blue one can make all colors in nature. These primary pigment colors are the secondary colors of light. With the primary colors needed to produce white light red, green and yellow one can make all the colors that one sees on the television screen. (Parramon, 12)

Using light filters from the theater department demonstrate combining primary light colors to get secondary light colors. Emphasize that combining light is an additive process, whereas combining pigments is a subtractive process. Any color that one sees is due to the light waves that remain after others are absorbed or transmitted. When one mixes two pigments, the number of light waves absorbed increases, while the number reflected decreases, making combining pigments a subtractive process. Mixing two pigments always decreases brightness. (Parramon, 14-16; Williams, Trinklein, & Metcalfe, 328-333)

(figure available in print form)

Explain that one can easily speak about light in terms of wavelengths, frequency, or energy, but color is a much more complicated topic to discuss. The transition from one color to the next is very gradual; the colors "merge." The difference between light of one wavelength and light at the next unit wavelength verges on the imperceptible. (Turner, 76) A combination of physical, chemical, physiological and psychological processes determine color vision. (Zollinger, 9) All people do not perceive colors identically; for instance people see colors such as gray, brown, and purple which are not even part of the spectrum. (Turner, 78)

Assignment: Activity: "Identification of Headache Remedies" based on chromatograms. (Handout, SHU April 28th Workshop. *Chemicals in Action* Ch. 3 "Separation of Matter" p.60)

Lesson Sixteen (two to three days) Interdisciplinary Activity with Visual Art's Teacher

Objective: To explore color theory of paints and pigments

Materials: Rice paper (very absorbent), primary colored drawing inks, pens, variety of

chemical glassware, flowers

Method: Teach students two basic Japanese brush strokes one creates bamboo; the

second creates flower petals or wings

Teach students how to load brush (creates different values)

Teach students about mixing pigment colors

Mix primaries to get secondary colors

Mix complements to gray down colors (changes saturation)

Using above techniques each student paints a picture combining chemical

glassware and flowers.

"Data": Terms and concepts students should fully understand: color wheel; primary,

secondary, intermediate, and complementary colors; hue (color), value

(lightness or darkness tint or shade), and saturation or intensity

(brightness or dullness)

Conclusion: Each student produces a painting and writes a paragraph explaining how his or her picture illustrates the above terms. Using a criterion sheet distributed at the beginning of the project students evaluate their own work before the teachers grade the activity. Attitude, careful use of materials, following directions, and wise use of time account for the 50% of grade determined by art teacher; writing accurate, complete definitions of terms and a clear insightful paragraph about their painting account for the 50% of grade given by chemistry teacher. Together with the art teacher we will again observe The Blacksmith's Shop to review hue, value, and saturation and note Wright's use of color.

Assignment: First Day Read The Visual Experience, "Color" pp.62-66

Second Day Complete write-up and evaluation for interdisciplinary project

After working with pigments to create an original painting and seeing how pigments interact with each other we find that several questions posed earlier again arise. What causes the color of a pigment? Why do pigments absorb particular rays and reflect others? The answers to these questions must be postponed until we've studied atomic structure. As the year progresses I will again return to the painting while teaching the following units:

1. Bright line emission spectrum, atomic structure, energy levels and electron Configuration return to light and color
2. Creation of elements interplay of religion and technology in painting
3. Ionic compounds, crystalline structure and transition metals exploration of most commonly used oil pigments and specific factors that cause colors. We will consider what pigments Wright might have used and which ones were not available to him. What do contemporary art students use in place of lead carbonate, an essential white pigment for Wright?
4. Organic chemistry interdisciplinary activity with visual arts teacher focused on art materials which exist as a result of chemistry. This activity emphasizes the influence of chemistry on art mediums and, therefore, artists. Before the advent of commercial pigments artists were more attuned to the chemistry of the materials they used; synthetic materials were unknown
5. Final visit to the Yale University Art Gallery Conservation Laboratory in the spring. By this time students should understand the basic principles behind the scientific equipment used and have some appreciation for the chemistry involved in preserving and restoring works of art. This visit will summarize and complete the idea that science and art are intimately related.

Narrative Background Information

Because this unit aims at approaching chemistry through art, it requires illustrating how I would do this in a series of lessons. At times the lesson centers on Wright's painting; at other times *The Blacksmith's Shop* primarily serves as the jumping off point that grounds chemistry facts and concepts in concrete reality. Always in the forefront of my thought is the idea that knowledge increases not only our understanding of the world, but also our appreciation. Studying color theory, using it to produce an individual painting, and examining its application in *The Blacksmith's Shop* enables us to see more in this painting.2 Learning and understanding how electron arrangement, crystalline structure, and atomic structure create color adds meaning to the study of difficult material and heightens an appreciation for the world of color we take for granted. The following narrative focuses on information unique to this unit; the annotated bibliography directs teachers to information not included in most chemistry texts.

Description of *The Blacksmith's Shop*

Paintings other than *The Blacksmith's Shop* could be used for this unit, but to use that painting effectively, the teacher needs to first describe the painting completely. The following description incorporates the detailed observations that the six student reports, combined, should include.

In *The Blacksmith's Shop* , an approximately 3 by 4 foot oil on canvas, Joseph Wright paints nine male figures, two horses and a dog inside a damaged building with the moon, partially obscured by clouds, peeking through an opening on the right. Various tools, horseshoes and other items litter the floor or hang from hooks. A patch of darkened sky shows through a hole in the roof. Three central figures standing around an anvil set on top of a tree stump focus intently on a piece of hot metal, which they are forging. In the right foreground one boy watches, one boy turns away, and an older man waits. Beyond an arched opening in the left background two other men and a dog huddle around a lighted candle looking at a horse's hoof while a boy holds the bridle of a second horse.

The three men grouped in the center are working on a long bar of iron which glows white hot at the larger end resting on the anvil, changes to red and then fades to black. The man on the left, his back to the viewer, grasps the cool end of the metal bar in his left hand, his arm extended in front of his body, and strikes the other end with a mallet clenched in his right hand. Sparks fly. The middle workman, who has a slightly receding hairline, faces forward with his left arm akimbo, curled fingers resting on his hip, wrist pointed down and palm facing his thigh. He twists his body to raise his right arm to shoulder height and bend his elbow forward and down. The first man's shoulder hides his right hand and all but the end of a handle from view. The workman on the right grasps a long handled sledgehammer with two hands, holding it above his left shoulder.

The workmen, all apparently clean-shaven, wear similar attire: white shirts with rolled up sleeves and a V-neckline opened almost to the waist. A long brown leather apron with a knee-height triangular tear, snug fitting brown britches with three buttons and a tie at the left knee, long socks tucked beneath the britches and bunched at the ankles, and buckled shoes complete the outfit of the man to the left. The middle workman's apron bib folds over at the waist.

The quality of the clothes of the three figures in the right foreground differs from that of the workmen. In the corner a clean-shaven older man with gray wavy hair and deep wrinkles creasing his brow straddles a gnarled log and rests his hands atop the handle of an upright mallet sitting on the log. A horseshoe hanging on the wall causes the mallet handle to resemble a cane. The man stares at the floor with downcast eyes. He wears a gray-green, knee length coat with brown lining, deep cuffs, and a matching wide brimmed, floppy, tam-like hat. The coat bunches on his upper left leg around one gold colored button. A touch of white protrudes below the left sleeve and a bit of gray-green waistcoat peeks from under his coat. A long matching scarf draped around his neck, brown britches and hose, and buckled shoes complete his attire.

Between the workmen and the seated man stand two boys, both with brown curly hair. The smaller lad inclines his head, turns away from the hot metal and covers his eyes. He wears a white shirt with collar and a red, "velvet" coat torn at the elbow and ending midway down his upper leg with ragged front edges. Three gold colored buttons decorate the front of his coat. His brown, snugly fitting pants, torn at the knee, gape open, exposing bare skin on his inner right leg. Unlike typical knee britches, these pants seem long enough to cover his socks above his instep. His left brown shoe lacks either a strap or buckle.

To the right stands a second, taller boy, his left hand in his pocket. His eyes are fixated on the workmen, but his right arm curls around the smaller boy's shoulders, hand bent upwards, shielding him from the glare. He wears a brown outer coat, white shirt, and a white "silk" scarf tied around his neck. His hiked up brown pants reveal his left knee and right calf. His socks bunch around his ankles above boot like shoes. A lace lies on the floor. Around his waist hangs a leather apron, one corner caught in a metal clasp.

A rounded arched entryway with an angel guarding the right side frames the remaining figures in the left background. A boy wearing a brown hat, black shirt and red-edged neckerchief watches the two men. The seated man wears brown a long coat, lighter britches, high boots and a narrow brimmed hat; all complemented by a white scarf tied around his neck. Hunched over, he points at the horse's hoof. A fourth workman bends over, left hand on his knee, and also looks.

The metal bar forms the dominant horizontal line, which extends to the back of the bent figure on the left and the top of the boy's apron on the right. Mortar between the bricks, pieces of twisted metal wire on the wall to the right, rows of horseshoes, and the ceiling beams beyond the arch echo this horizontal line. Architectural features such as pilasters, the sides of arched openings, and a brick wall protrusion, along with the standing figures, create vertical lines. A broken piece of wood dangling from the ceiling points to the vertical begun by the smaller boy's left leg and continuing up a column. The central man's right leg, head, and the shadow on the wall form another strong vertical. Ceiling beams and lines on the brick floor form background diagonals, but the most powerful diagonal passes from the upraised mallet down the swinger's forearm across creases in fellow workmen's apron and britches to the toolbox on the floor. The line from the older man's bent legs to light on the taller boy's calf, and the line from the light on his face to the light reflected on the larger boy's apron to the end of the smaller boy's red coat, together with the lines of the middle workman's forearms, run parallel to this diagonal.

Arches, heads, hats, the moon, horseshoes, the tops of stumps, shoulders, ears, curled hands, and bent knees and elbows provide a variety of curved lines, circles and ovals. Triangular shapes range from the tiny apron tear, to the straining tendons in the workman's neck, to the spaces between legs and arms, to the slightly irregular patch of sky in the ceiling and the tall shadow cast on the wall behind the workmen.

The metal bar provides the main source of light, but the moon and candle also shed light. The heated bar and the men's white shirts gleam most, but the moon, cloud edges, candle, and reflections on skin and clothing also glow. Darkness obscures the edges of the painting. Rusty red dominates the building stone, occasionally intensified in reflections on the hanging aprons, the bar, the red coat, and flushed cheeks. Brown dominates the clothing. The sky appears blue-gray.

Textures run the gamut from silky smooth scarves to rough stone and mortar. They include hair (both human and animal), hooves, skin, metal (both burnished finished products and coarse twisted wire), leather, fabric (cotton, wool, velvet, felt), wood, ashes, dirt, wax, and sweat.

Looking down from above one sees a triangular hole in the roof and the rectangular outline of an entire building or part of a building. Within the shop one notes circular heads and tree stumps, rectangular floor bricks, and three triangular groupings of people. Two groups almost touch. Bright light emerges from the center of one group, pale light from the center of a second group on the left, and the third group only reflects light. A long narrow rectangle, the beam bracing the walls, divides the scene while creating a powerful horizontal in three dimensions.

Deduction *The Blacksmith's Shop*

Again, if the teacher selects a different painting she/he needs to carefully make deductions before asking the class to do this difficult exercise. It is very easy to inadvertently jump from observation to deduction, from deduction to speculation. The scientific method demands that we proceed cautiously and meticulously.

Anyone observing Joseph Wright's painting could readily entitle it *The Blacksmith's Shop* based on the anvil and other equipment and tools pictured, the suspended action of the three central figures, and the horseshoes hanging on the wall. The white hot metal on the anvil, together with the light shining through the apron tear, implies that an unseen fire burns in front of the man with his back to the viewer. A burning fire in a building requires a chimney for the smoke to exit. The brick protrusion, a chimney just to the right of the pilaster on the left, projects through the ceiling like an addition to the original structure. This implies that the blacksmiths adapted this abandoned building for their use. The crumbling walls and missing roof suggest abandonment.

The twisted position of the central figure with his raised right elbow, combined with the end of the handle just visible beyond the first man's shoulder, intimates he is operating the bellows, an essential piece of equipment in a blacksmith's shop. The bellows is required to increase the supply of air, hence oxygen, to the burning material to intensify the heat. The apparatus below the hanging aprons looks like a bellows and is properly positioned in relation to the unseen fire and chimney. We do not know what fuel burns, but the presence of tree stumps suggests wood. Posing coal as a possibility requires further research.

The stance of the man on the left with a sledgehammer raised over his shoulder suggests that he will strike the hot metal bar in order to flatten and shape it. The two men holding mallets probably strike the metal alternately, the longer handled sledge-hammer more suited to flattening because of the increased force it exerts, the shorter handled mallet for shaping because it is easier to control. The fact that the bar is heated indicates that heating iron makes the metal more malleable. The items hanging on the wall and lying on the floor give clues to possible pieces they are forging. The group on the left looking at the horse's foot implies the horse needs a new shoe and they are waiting for this shoe. Horses need metal shoes to prevent their hooves from wearing down when they carry or pull heavy loads or travel on hard surfaces.

The anvil provides a sturdy, non-flammable surface for the blacksmith's work. The stump raises the anvil to a convenient working level while providing a firm foundation. The leather aprons protect the workers from flying sparks and hot metal. The pole above the workmen's head suggests that the walls need bracing to prevent collapse. It, like the stump and their location in an abandoned building, imply that the blacksmiths are relatively poor but resourceful.

The sound of ringing metal drowns the murmur of voices from the group huddled on the left, the crackling fire, and the "swoosh" of air rushing from the bellows. Occasionally metal pieces lying on the floor, accidentally kicked together, clank, or a startled horse neighs and stomps. The stench of sweat mingles with the smell of horses, fire, decaying wood, and overall mustiness. Every once in awhile a gust of wind blowing through the broken walls on the right soothes and cools the over-heated figures around the anvil.

The blacksmiths' work fascinates the young boys to the extent that the older boy even dons a workman's apron. However, the intense light and flying sparks frighten the smaller boy, causing him to turn away. The other boy appears older, not only because of his added height, but, more importantly, because of his protective attitude toward the smaller boy. The physical closeness of the two boys and the larger boy's encircling arm hint that they might be brothers, perhaps twelve and eight years old.

Viewing this painting one senses the passage of time. First, day passes evidenced by the moon and lighted candle. Blacksmithing normally proceeds during daylight hours; what causes the workmen to labor so arduously into the night? Second, time passes over generations highlighted by the young boys who merely watch the skilled workmen who exude power. The workmen who have mastered their craft actively contribute to society; the older man on the right sits and contemplates them, his hands resting on the mallet that once he, too, might have wielded. Finally time passes over the ages as illustrated by the collapsing church.

Longer examination and contemplation of the painting begin to lead to speculation and a need for research. The ornate angels over the arched entryway suggest that this was a Roman Catholic Church or, at least, definitely not a protestant church. By locating the blacksmith's shop in an abandoned church, Wright intimates that God blesses the labors of the working man. The smithies provide a service for their fellow man. The light shines on their endeavors as they use their talents to solve a problem a horse in want of a shoe, a worker in need of a tool, a traveler in search of a wagon part and the shadow of their work points toward the heavens. The older man's clasped hands resting on the workman's mallet mirrors the stance of a person in prayer. He completes the cycle of life from inexperienced youth to the wisdom of old age. He reflects on the passage of time and power.

Why are the smithies laboring into the middle of the night? Is it because they are poor and are "moon lighting"? Are they working overtime? Why are the two boys and older man out at night? Are they traveling with the man on the left, related to the blacksmiths, or poor boys, intrigued by the working of a forge, who have come during their only free time? The boys torn and disheveled clothing suggests either poverty or an accident. The older man in the front foreground appears unhurt, but the man on the far left seems to be discussing the condition of the horse's hoof with a fourth workman, similarly attired, to those working on the metal bar. The disarray of both boys hints that either the horse they were riding together stumbled and threw them, or a mishap befell the coach in which they were all traveling, but as this is not something with which everyone would agree, it is again speculation, not deduction.

Despite the speculative possibility of an accident, this scene, seen from a position just out of the painting foreground to the left of the pensive older gentleman, fills the viewer with a sense of peace and appreciation for the dignity of man and his work. The warm rosy glow that surrounds the workers and spreads outward in all directions suggests that all will end well. The smithies exude an air of power, strength, and competence; the older gentleman, of patience and acceptance; the older boy, of eager interest in the adventure. The moonlight heightens the feeling of peace; the clouds will pass; the difficulties will end.

The preceding material provides the information needed to use *The Blacksmith's Shop* to introduce topics in chemistry and a variety of lessons for approaching science via art. Numerous other possibilities for enriching standard chemistry units and pursuing art-science research remain. When discussing electron configuration and the transition elements one can examine the standard paints used by artist and the effect of unfilled orbitals on color. Studying ionic compounds affords an opportunity to note the effect of crystalline structure, as well as particle size, on the scattering of light and, hence, color. Organic chemistry, which essentially started with color and the dye industry, invites questions on the differences between pigments and dyes, pigments used by the old masters versus pigments used by today's artists, the structure of organic pigments, and the causes of color in these compounds. In organic pigments, just as in inorganic pigments, electrons play a major role. All organic pigments contain areas of high electron density and contain double bonds, aromatic rings, or electronegative atoms. (Turner, 77)

As one delves deeper into the basic cause of color, more and more knowledge that is not included in a standard chemistry text is required. The annotated bibliography that follows directs teachers to this material and, I hope, will spark additional inquiries.

Notes

1 Primary colors can be very confusing. Although most textbooks list primary pigments as magenta, cyan blue and yellow, some simplify the colors and say red, blue and yellow. Hobbs does this but the color diagram that he uses has these same colors listed as magenta and cyan.

2 "In some tribal cultures color is not very important…. In one culture the people had words only for light and dark and the color red." (Hobbs, 70)

Teacher Bibliography

Armitage, F., *The British Paint Industry* . Oxford: Pergamon Press, 1967. This text is especially useful for determining the pigments available to and probably used by Wright.

Boynton, Robert M., "Color," pp. 180-181 in *McGraw-Hill Encyclopedia of Physics* , 2nd ed. Ed. Sybil P. Parker. New York: 1991. This article discusses the use of the spectrophotometer and explains the CIE chromaticity diagram.

Brown, Frederick C., "Color Centers," pp.182-184 in *McGraw-Hill Encyclopedia of Physics* , 2nd ed. Ed. Sybil P. Parker. New York: 1991. This article explains atomic and electronic defects that produce absorption bands in normally colorless crystals. Gamma or x-ray radiation, impurities and sometimes electrolysis produce color centers.

Edgerton, Judy, *Wright of Derby* . London: Tate Gallery Publications, 1990. Published by order of the trustees on the occasion of exhibitions that year at the Tate Gallery, The Grand Palais in Paris and Metropolitan Museum of Art in New York city.

Feitknecht, W., "The Theory of the Color of Inorganic Substances," pp. 1-25 in *Pigments: An Introduction to their Physical Chemistry* . Ed. David Patterson. Amsterdam: Elsevier Publishing Company, LTD., 1967. This text is both technical and mathematical. Chapter 1 is extremely valuable for explaining the part electrons play in determining color. Compounds containing the same metal in two different valence states are colored because the energy jump from one state to the next is not excessive. For example, the intense color of Prussian blue is caused by the presence of Fe2+and Fe3+ ions, KFe3+éFe2+(CN)6ù. The text clearly explains the effect of filled and unfilled s, p, or d orbitals on color.

Feynman, Richard P., Six Easy Pieces: *Essentials of Physics Explained by Its Most Brilliant Teacher* . Reading, MA: Addison Wesley Publishing Co., 1995. Taken from Feynman's lectures, these are superb essays that explain very difficult subjects. The essay on energy is particularly applicable.

Gamow, George, *Thirty Years That Shook Physics: The Story of Quantum Theory* . Garden City NY: Anchor Books, Double Day & Co. Inc., 1966. Extremely well written with numerous illustrations and personal anecdotes, this book clearly explains the tremendous discoveries concerning the structure of the atom without burying the reader in mathematics. Chapter I, "M. Planck and Light Quanta" and Chapter II, "N. Bohr and Quantum Orbits" are especially applicable. Gamow clearly explains the relationship between the electromagnetic emission spectrum, astronomical observations and atomic structure.

Huey, S.J., "Color in Paint," pp. 456-494 in *Technology of Paints, Varnishes and Lacquers* . Ed. Charles R. Martens. New York: Reinhold Book Corp., 1968. Huey discusses the scientific foundation of the three dimensions of color and the importance of the spectrophotometer, the primary instrument for the precise measurement of color. Because "Color is a psychophysical reaction as seen by the eye and interpreted by the brain" (456) it is important to have a plot of the characteristic curve produced by the light reflected from a sample, a "fingerprint of the color." The shape of this curve remains constant, even if the pigment is mixed with other pigments and, therefore, provides a permanent color record.

Jefferies, H.D., "Dispersion of Inorganic Pigments," pp. 308-409 in *Dispersion of Powders in Liquids With Special Reference to Pigments* . Ed. G.D. Parfitt. New York: John Wiley & Sons, 1973. This chapter provides information concerning the effects of particle size on light scattering and, thus, color, as well as the components and manufacture of pigments. There are synthetic red iron oxides differing only in particle size ranging from 100nm, a pigment with a strong yellow cast, to 1000nm, a pigment with a strong violet cast. Jefferies also offers helpful background concerning hue, value and saturation. The spectral reflectance curve usually shows a peak corresponding to the wavelength of the major color of the pigment. However, "Some nominally 'pure' pigments have secondary peaks, while purple has concave curves with reflectance increases at both blue and red ends." (317) Colors that completely reflect light over a small range of wavelengths, producing a sharp, narrow peak, are the most saturated.

Jenkins, Francis A. and Watson, William W., "Huygens' Principle," p. 553 in *McGraw-Hill Encyclopedia of Physics* , 2nd ed. Ed. Sybil P. Parker. New York: 1991. This brief article provides interesting historical background on light. In the seventeenth century, Newton postulated that light was a particle at the same time that Huygens hypothesized that light travels in waves. Fame triumphed, and Newton's ideas predominated until the middle of the 19th century.

Levison, Henry W., "Pigmentation of Artists' Colors," in *Pigment Handbook: Applications and Markets* Vol. II. Ed. Temple C. Patton. New York: John Wiley & Sons, 1973. This reference provides valuable historical background on pigments for any medium.

Mayer, Ralph, *The Artist's Handbook of Materials and Techniques* . NY: Viking Press, 1964. This comprehensive text is written for artists by a chemical researcher in the paint, varnish and pigment industry who is, himself, a painter.

Nicolson, Benedict, *Joseph Wright of Derby: Painter of Light* . Vols. I, II. New Haven: Yale University Press, 1971. This text provides essential background material on Joseph Wright and his paintings.

Parramon, Jose M., *Color Theory* . New York: Watson-Guptill Publications, 1988. This text clearly presents the historical development of color theory as it relates to both light and pigments, the effect of different light sources on color, and the development of synthetic organic pigments. Parramon lucidly illustrates how the interaction of adjacent colors affects the color one sees. The phenomenon of successive images, credited to the physicist Chevruel, suggests a fascinating brief exercise. Stare at images of three primary pigments for thirty seconds and then look at a white background. You will see complementary colors. This explains why colors cast their complementary colors onto adjacent colors or shades.

Prown, Jules D., "Mind in Matter: An Introduction to Material Culture, Theory and Method," pp. 7-10 in *Winterthur Portfolio* , Vol. 17, no. 1 Spring 1982. This article is essential to an understanding of object analysis.

Rohr, Walter, *Teaching Atomic Structure in Color* . Fairfield, CT: Printed handout from Workshop presented Mar. 19, 2001 by CT Chemistry Teacher Association and SHU Smart Center at Sacred Heart University, Fairfield, CT., 2001.

Stroke, George W., "Light," pp. 679-687 in *McGraw-Hill Encyclopedia of Physics* , 2nd ed. Ed. Sybil P. Parker. New York: 1991. This article, which comes with an extensive bibliography, is especially helpful for the historical development of theories concerning light.

Turner, G.P.A., *Introduction to Paint Chemistry and Principles of Paint Technology* . New York: Chapman and Hall, 1988. This text provides invaluable information on the cause of color in both inorganic and organic pigments. Turner discusses the influence of ligands and their relationship to transition elements with unfilled d or f orbitals, the charge transfer mechanism for absorption spectra, and the structure of numerous organic pigments.

Zollinger, Heinrich, *Color Chemistry: Syntheses, Properties and Application of Organic Dyes and Pigments* . Weinheim, Fed.Rep. of Germany, 1987. This text, which contains numerous organic structures, is especially helpful for understanding the history of color and the uses of dyes and pigments as well as the difference between the two. Zollinger includes a fascinating section on fluorescence and the structural difference between phenolphthalein, which does not fluoresce and fluorescene, which does.

Student Bibliography

Hobbs, Jack and Salome, Richard, *The Visual Experience* . 2nd ed. Worcester, MA: Davis Publications, 1995. This visual arts textbook explains color theory and color dimensions in simple terms with numerous examples of artwork.

Hurd, Silver, Bacher, and McLaughlin, *Physical Science* . 1st ed. Englewood Cliffs, NJ: Prentice Hall, 1988. This 9th grade text provides a helpful review of light. More recent editions are available, but I have multiple copies of this edition that students can borrow.

Tattersall, Bruce, *Stubbs and Wedgwood* : Unique Alliance Between Artist and Potter, with an introduction by Basil Taylor. London: Tate Gallery, 1974. This book will be especially helpful for students who want to research Stubbs, a contemporary of Wright, and his paintings on Wedgwood plaques.

Tocci, Salvatore and Viehland, Claudia, *Chemistry: Visualizing Matter* . New York: Holt, Rinehart and Winston, 1998. This standard student text is excellent for diagrams and illustrations, but sometimes lacks explanatory text.

Williams, Trinklein, and Metcalfe, *Modern Physics* . New York: Holt, Rinehart and Winston, 1980. This text contains a clearly written section on light, pp.328-333, which incorporates six additional full pages of colored plates illustrating colors, filters, prisms, emission spectra, and interference patterns.

Zakia, Richard D. and Todd, Hollis N., *Color Primer I and II* . Dobbs Ferry, NY: Morgan & Morgan, Inc. Publishers, 1974. This small text presents color theory in easily understood language.

Video Materials

Color and Light, Science in Action . Huntsville, Texas: Educational Video Network, Inc.