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ABSTRACT

This document describes a two-year integrated biology and chemistry curriculum for ninth and tenth grade students. The first chapter outlines the rationale for integrating biology and chemistry and presents the topic sequence for the integrated curriculum. Chapter 2 discusses the developmental, cognitive, and philosophical issues that form the theoretical framework for this integrated curriculum. Chapter 3 includes lesson plans from the first unit of the integrated curriculum which demonstrate how the theoretical issues discussed in Chapter 2 can be applied in the classroom. Chapter 4 details the curricular implementation process over the past 2 years and indicates potential future directions. Contains 79 references. (JRH)

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An Integrated Biology and Chemistry Curriculum

Submitted for

TA5587 Klingenstein Seminar

Klingenstein Project

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By

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Chapter 1 - Introduction

Most high school science curricula resemble the model below:

9th Grade	Earth Science
10th Grade	Biology
11th Grade	Chemistry
12th Grade	Physics

Described as the "layer cake" approach, it splits the study of science into separate disciplines, allowing efficient learning as students progressively master closely related concepts (DeBoer 1991, p.222; Jacobs 1989, p.7). This approach matches the National Education Association's Committee of Ten recommendations for high school science education:

9th Grade	Physical Geography
10th Grade	Biology
11th Grade	Physics
12th Grade	Chemistry

Minor changes have occurred--Physical Geography was reconfigured as Earth Science, and chemistry and physics were transposed--but the layer cake approach has remained identical. The surprising point here is that the Committee of Ten formulated their recommendations in *1893* (Krug 1964, p. 59).

The Committee of Ten--six college presidents, the U.S. Commissioner of Education, and three high school principals--convened with the charge to address the transition between high school and college and, specifically, to simplify the crowded high school curriculum. Throughout the 1800's, America shifted from an agrarian to an industrial society and increasing numbers of students attended high school. To accommodate new interests and abilities, schools offered a wider variety of courses than the classic curriculum of Greek, Latin, and mathematics. In their study of 40 secondary schools, the Committee of Ten found that schools offered over 40 different science courses of variable length. Some courses were taught for such a short time that they were thought to be of little value (Andersen 1994, p.49). Among its final recommendations, the Committee of Ten suggested that high schools focus on only the four science courses listed above.

Although enrollment had increased, high school remained an education for the elite. In 1900, less than 10% of the available population (ages fourteen to seventeen) attended high school (Powell et al. 1985, p.339). This elitism is clear in the language used by the Yale Report of 1828 that commented on the intrusion of so-called modern subjects.

> The study of classics is useful, not only as it lays the foundation of a correct taste, and furnishes the student with those elementary ideas which are found in the literature of modern times, and which he no where so well acquires as in their original sources;--but also as the study itself forms the efficient discipline of the mental faculties... Every faculty of the mind is employed; not only the memory, judgement, and reasoning powers, but the taste and fancy are occupied and improved...
>
> The proper question is,--what course of discipline affords the best mental culture, leads to the most thorough knowledge of our own literature, and lays the best foundation for professional study. The ancient languages have here a decided advantage (Yale Report of 1828, in DeBoer 1991, p.4-5).

As we know, science did ultimately find a place in the curriculum. The Committee of Ten secured its place by promoting science education since it, too, could train the mind (Krug 1964, p.87). The effect of the Committee of Ten recommendations was to formalize the order and placement of the scientific disciplines into separate, sequential boxes.

While there have been calls for educational reform in every decade of the twentieth century (Lieberman 1994), they have resulted in incremental changes within the discipline boxes, but little fundamental restructuring of the boxes themselves. As science and technology have undergone exponential growth over the past century, educators changed the content--mostly the *addition* of content--but left the broad structure of science education intact.

In this document, I will describe a project of fundamental change taking place at University High School (UHS) in San Francisco, CA where I am the science department chair. Over the past two years, four science teachers (Ray Boyington, Ann Pogrel, Rob Spivack, and I) have been developing a two-year integrated biology and chemistry curriculum for ninth and tenth grade students. We will implement the first year of this program in the fall of 1995. In the remainder of this chapter, I will outline my rationale for integrating biology and chemistry, and present the topic sequence for our integrated curriculum on page 9. In Chapter 2, I will discuss the developmental, cognitive, and philosophical issues that comprise the theoretical framework for this integrated curriculum. In Chapter 3, I have written eleven lesson plans, the first unit of the integrated curriculum, which demonstrate how these theoretical issues can be applied in the classroom. As we endeavored to change the curriculum, we realized that we should also consider changes in our methods of instruction, i.e., making each class more student-centered and inquiry-based and less teacher-centered and fact-transmission. Chapter 4 details the curricular implementation process over the past two years and indicates potential future directions.

Rationale

> To the young mind everything is individual, stands by itself. By and by, it finds how to join two things and see in them one nature; then three, then three thousand; and so ... it goes on tying things together, diminishing anomalies, discovering roots running underground whereby contrary and remote things cohere and flower out of one stem... The astronomer discovers that geometry, a pure abstraction of the human mind, is the measure of planetary motion. The chemist finds proportions and intelligible method throughout matter; and science is nothing but the finding of analogy, identity, in the most remote parts.
>
> Ralph Waldo Emerson, *The American Scholar*
> Harvard Commencement 1837

We require students at UHS to take two years of laboratory science: one year of natural science (biology) and one year of physical science (chemistry or physics). This requirement matches the University of California admissions policy where approximately 30%-40% of our graduates enroll each year (see Appendix - Application for Curriculum Approval). I will explore three factors in my rationale for integrating biology and chemistry; 1) the disciplines of biology and chemistry increasingly overlap, 2) the rapid of growth of knowledge within the fields of biology and chemistry, and 3) the increasing diversity of the students.

1) *Biology and chemistry increasingly overlap.* The argument for studying the disciplines separately now applies to integrating biology and chemistry; the two fields increasingly use similar and/or related concepts. For example, understanding the importance of the molecule, DNA, requires the study of topics traditionally taught in biology such as genetics, evolution, cells, and organelles, as well as the study of chemical topics such as molecular structure, bonding, and atomic theory. An integrated biology and chemistry course would gain synergistic benefit from both disciplines. On the one hand, chemistry provides the conceptual underpinnings for many biological phenomena, such as the energy pyramid or

molecular genetics. Biology teachers often must resort to unsatisfactory, superficial "handwaving" explanations, and the near-apology "you'll learn more about this next year ..." Without proper chemical foundation, we compel biology students to memorize material. On the other hand, biology provides meaningful context for chemical concepts such as kinetics and the atomic theory. The level of abstraction in chemistry can make it one of the most difficult (and frankly, boring) courses for high school students. This integrated course offers a logical presentation of the material that takes advantage of this synergistic relationship. Many complex issues in science--such as ecological problems or biotechnological advances--are appearing on ballot initiatives and in front page newspaper stories. If students are to understand, and soon make informed decisions on these issues, they must possess an integrated understanding of the sciences. In the words of Emerson cited at the beginning of this section, an integrated curriculum will help students find those "roots running underground whereby contrary and remote things cohere and flower out of one stem."

2) *The growth of knowledge* - The issue of biotechnology points out the rapid pace of scientific advance; biotechnology did not exist 25 years ago. There exist over 70,000 scientific journals publishing new research findings weekly, monthly, or quarterly. 29,000 of these journals are new since 1970 (Hurd 1995, p.6). We cannot continue to simply add new discoveries on top of an already crowded curriculum. These discoveries bring with them new technical terms--most are "words students have never seen before today's assignment, have never heard pronounced, and will likely never use in a conversation the rest of their lives. Science textbooks, of necessity, have had to increase in size to accommodate these new terms

and today are considered as among our most beautifully illustrated dictionaries" (Hurd 1995, p.4). We can no longer try to teach everything (if we ever could). Students must understand underlying concepts if they are to make sense out of the voluminous information. An integrated course with its emphasis on the connectedness of knowledge, rather than the amount of knowledge, can provide students with this understanding.

3) *The increasing diversity of students.* Although my arguments in this paragraph could equally apply to the changing demographics and increasing multiculturality of American society as well as to gender issues in science (which I will address in Chapter 2), I will focus instead on the historical perspective of science education raised in the introduction. After science found a place in the curriculum at the end of the last century, science instruction adopted many of the same styles and techniques used in the instruction of the classics; the classroom was teacher-centered, the teacher style was authoritarian, and students relied on rote memorization. The best science students may have survived such a regime, but most students were left out.

> Now, what I want is, Facts. Teach these boys and girls nothing but Facts. Facts alone are wanted in life. Plant nothing else, and root out everything else. You can only form the minds of reasoning animals upon Facts: nothing else will ever be of any service to them. This is the principle on which I bring up my own children, and this is the principle on which I bring up these children. Stick to the Facts, sir!
>
> Charles Dickins, *Hard Times* (in NSTA 1993, p.1)

Unfortunately, the approach of Dickens' schoolmaster is familiar to far too many science students today. As another century comes to a close and America (and the world) changes from an industrial to an information era, all students will need to be scientifically literate. We can no longer teach the sciences to an elite. To achieve the goal of *Science for All Americans* (title of 1989 report by the American Association for the Advancement of Science), we need to tailor the approach of science education to a more diverse student body. An integrated curriculum better meets developmental needs of all students than can separate courses; topics can be sequenced by their cognitive demands, rather than by their discipline placement. This last part of the rationale will be developed further in the theoretical framework.

This general argument also fits the specific situation of science education at my school, University High School (UHS). Most students at UHS (90%) had taken biology in the ninth grade. We had advised the remaining five to 10 ninth grade students to defer taking biology when we felt that they might anticipate difficulty with the more abstract material and larger concepts. However, these deferred students understandably felt stigmatized, labeling themselves as not "science people." Our good intentions systematically excluded a segment of the student body from pursuing further science courses. We want to eliminate this tracking of students and include all ninth grade students in science education. I feel that an integrated curriculum will be more inclusive by postponing the more abstract material to the second year when students might be developmentally ready.

The Curriculum

Topics in Biology

Topics in Chemistry listed in italics

Integrated Biology and Chemistry I - Ninth Grade

A. What is science?/What is life?
B. Introduce Human Biology/Respiratory System
C. Gases - composition/combustion products
pressure-volume relationship
D. Diffusion - particle model
C. Osmosis/Circulatory System
F. Combustion/Qualitative Energetics
G. Descriptive Kinetics
H. Digestive System/Excretory System
I. Reproductive System
J. Diversity of Life (Five Kingdoms)
K. Chemical Separations
L. Ecology

Integrated Biology and Chemistry II - Tenth Grade

M. Atomic-molecular theory
N. Electronic structure of atoms
O. Molecular structure
P. Physical properties
Q. Chemistry of organic functional groups
R. Biomolecules - Carbohydrates, lipids, nucleic acids, proteins
S. Stoichiometry
T. Energetics - quantitative
U. Aqueous solutions
V. Kinetics - quantitative
W. Cells/organelles
X. Acid/base
Y. Equilibrium - quantitative
Z. Reduction/oxidation reactions
A'. Tools of Biotechnology
B'. Genetics
C'. Evolution/History of Life

Chapter 2 - The Theoretical Framework

While this two-year integrated curriculum "covers" most of the topics typically found in separate one-year biology and chemistry courses, the philosophy behind this curriculum is to "uncover" student interest and student questions. The curriculum emphasis is the process of learning (how we know) rather than the products of learning (what we know).

In this chapter, I will provide the theoretical framework for integrating biology and chemistry and, in addition, I will segue from the general curriculum on page 9 to specific lesson plans detailed in Chapter 3. The first section of this chapter describes the match between the topic progression of this integrated curriculum and the developmental and cognitive needs of a diverse student body--the third point of my rationale. The second section examines issues to related cognitive development described by the philosophy of constructivism. In the third section, I will discuss the learning cycle and collaborative learning as pedagogical applications of constructivism and I close this chapter with my approach to assessment and evaluation.

Developmental/Cognitive Issues

> Just emerging from childhood, trying earnestly to steer toward the fog-enshrouded world of adulthood, young people of this age are vulnerable but highly responsive to environmental challenge. This time provides an exceptional chance for constructive interventions that can have lifelong influence.
>
> David Hamburg (1989, p.4)
> Carnegie Task Force on Education of Young Adolescents

Although the Carnegie Task Force study focused on middle schools, Hamburg's observations on 'young people of this age' can easily apply to ninth and tenth grade students. Students' experiences in these grades have a powerful influence over their feelings about school, about specific subjects such as science, and about themselves as learners. Thus, schools, and by extension the curricula, should challenge students while remaining sensitive to their cognitive needs.

In the development of this integrated curriculum, I and other members of the science department at UHS drew upon the work of Jean Piaget whose theories have dominated the field of cognitive development since the 1950s. Although Piaget devoted little attention to educational practice, his theories can help curriculum development (Ginsburg and Opper 1988, p.237). In particular, we referred to his description of adolescent cognitive growth in terms of abstract reasoning, i.e., suggesting transitions from concrete to formal reasoning. Concrete reasoning students focus on the reality of a situation; their thought is limited to the information available to immediate perception. By contrast, formal reasoning students can imagine the possibilities inherent in a situation; their thought is flexibly adapting to unexpected results

(Keating 1990, p.58). Our students are in the midst of this transition.

Piaget outlined three factors that he believed influenced the transition from concrete to formal thinking: 1) the brain maturation occurring at the time of puberty, 2) an individual's experiences with the environment and his/her response(s) to these experiences and, 3) the social environment--an aspect of the individual's environment worthy of separate note (Ginsburg and Opper 1988, p.205). The Russian psychologist, Lev Vygotsky, further elaborated on the importance of social interactions in cognitive development (Vygotsky 1978). Piaget's emphasis on brain maturation, which he believed was the foundational basis for formal thought, explains why his theories were not initially applied to education. What role could educators play in a process that developed naturally? Piaget second and third influences, which were less emphasized, do fall under the domain of education. In the remainder of this section, I will discuss curriculum development in light of Piaget's second influence on cognitive growth, the ordering of students' experiences. I defer discussion of his third influence, the effect of socialization on learning, to a later section on collaborative learning.

I will argue that the topic order in this integrated biology and chemistry curriculum better matches the cognitive development of young adolescents than that of separate courses. As I introduced earlier, topics in an integrated curriculum can be sequenced based on their cognitive demands, rather than their discipline placement. Before proceeding, I begin with a caution--gauging the cognitive demands or the abstraction of a concept remains intuitive at best and inexact at least (White 1994, p.257). I will use one author's suggestion of the characteristic of perceptibility as a useful measure of abstraction (Herron 1978, p.168). Concepts that are perceptible, such as solids and liquids, may be thought of as concrete; while those that are imperceptible, such as atomic theory, are abstract.

This integrated curriculum begins with observable phenomena. The biological topics (left column on page 9) progress from the macroscopic (organisms and ecosystems) to the microscopic (cells and molecules), while the chemical topics (right column on page 9, in italics) progress from the descriptive and qualitative to the theoretical and quantitative. Specifically, we begin with the study of the organism most familiar to the students--*Homo sapiens*. The more abstract, less perceptible biological concepts, such as molecular genetics, are moved back into the second year of the curriculum, while the descriptive elements of chemistry, such as gases, are moved forward into the first year. Unfortunately, most textbooks are organized in the reverse order from the one suggested here. Biology texts begin a superficial treatment of chemical principles, build up to cells, and end with organisms and ecosystems. Chemistry texts begin with the atomic theory and end with descriptive chemistry (Herron 1984, p.852). This organizational scheme makes sense to the mature adult mind, not to the novice (DeBoer 1991, p.160; Bunce 1995).

In the first year, biological topics dominate this integrated curriculum. As students study biological phenomena, they uncover "a need to know" the underlying concepts in chemistry. For example, as students study the mechanics of breathing, they discover the relationship between gas volume and gas pressure (called Boyle's law). When the diaphragm moves down and the volume of the chest cavity increases, the pressure in the chest cavity decreases and air rushes in the only available opening ---the nose and/or mouth--to inflate the lungs. In contrast, traditional courses segregate the study of these topics to different years, the study of the lungs in biology and the study of Boyle's law in chemistry.

In the second year, chemical principles drive the curriculum. Topics introduced qualitatively in the first year (kinetics and energetics) are revisited quantitatively in greater depth and with greater rigor--a 'spiral approach' as suggested by Bruner (1960, p.52). This approach takes advantage of the spacing effect. Studies have shown that spaced presentations yield substantially better learning than do massed presentations (Dempster 1988). In addition, this approach guards against the students' developing a "vaccination theory" of education--as in, "we've had that, we don't need to know it anymore" (Fogarty 1991, p.5). Dewey (1938) used a similar teacher-as-physician metaphor when he referred to students receiving their prescribed "dose" of learning (p.46).

> The "spiral curriculum." If one respects the ways of thought of the growing child, if one is courteous enough to translate material into his [or her] logical forms and challenging enough to tempt him to advance, then it is possible to introduce him [or her] at an early age to the ideas and styles that in later life make an educated [person]. We might ask, as a criterion for any subject taught in primary school, whether, when fully developed, it is worth an adult's knowing, and whether having known it as a child makes a person a better adult. If the answer to both questions is negative or ambiguous, then the material is cluttering the curriculum.
>
> Jerome Bruner (1960, p.52) *The Process of Education*

In a spiral curriculum, students come to have a deeper understanding of concepts, as they see long-term relevance and utility to their learning. "Cognitive growth occurs when an individual revisits and reformulates a current perspective" (Brooks and Brooks 1993, p.112). This integrated curriculum ends with units on biotechnology, genetics, evolution, and the history of life (see bottom of page 9) which provide an appropriate closure--students must synthesize their understanding of both biology and chemistry to explore these topics.

One might question whether this integrated curriculum is a better learning experience for all students--What about those students who achieved success in traditional courses? I would respond that an integrated curriculum, with topics sequenced from concrete to abstract, also provides a better learning experience for advanced science students, those that have achieved formal reasoning. Piaget argued that everyone reverts to concrete thought when facing new situations (Herron 1978, p.167). By initially providing concrete representations of a concept, students are given something to "fall back on" when they cannot formally deduce a relationship. An illustrative anecdote: The Massachusetts College of Pharmacy recently instituted a coordinated biology and chemistry curriculum. In discussing thermodynamics--a particularly difficult, mathematics-intensive concept--Vin LoPresti commented, "You know, I could apply the rules quantitatively, but I never learned it qualitatively until ... this coordinated course." He had learned to apply algorithms, but had not understood the idea in a 'deep' sense. Significantly, LoPresti is not a student in this course; he is the *chemistry professor*. The words that I left out of his quotation were "until *I taught* this coordinated course" (Garafalo and LoPresti 1993; LoPresti and Garafalo 1987; Garafalo and LoPresti 1986). Connecting topics in biology and chemistry is a better approach to learning *and teaching* the material. "Teaching must not miss opportunities for encouraging students to perceive links between topics. Apart from the deeper understanding that will follow, connectedness is at the heart of science. Without connectedness, science is not a system capable of further advance, but a collection of eclectic trivia" (White 1994, p.261).

Constructivism

Connectedness also lies at the heart of a branch of epistemological philosophy called constructivism, an outgrowth of the work by Piaget. Although he is often identified as a psychologist and his theories are now popular within educational circles, Piaget began his career interested in epistemology. He studied children because he believed that an understanding of human knowledge could only result from study of its formation and evolution (Ginsburg and Opper 1988, chapter 1). In 1971, Piaget wrote:

> The current state of knowledge is a moment in history, changing just as rapidly as knowledge in the past has changed, and, in many instances, more rapidly. Scientific thought, then, is not momentary; it is not a static instance; it is a process. More specifically, it is a process of continual construction and reorganization (Brooks and Brooks 1993, p.25).

For the individual, this process of construction depends on connecting new experiences with prior knowledge.

Contrast this constructivist view of knowledge with objectivist epistemology, the legacy of seventeenth century philosophers Isaac Newton and Francis Bacon (DeBoer 1991, p.198). To the objectivist, knowledge exists independently of the knower and can be experienced objectively. By this view, absolutely true discoveries can be made by suitably trained observers. Applying this to education leads to a classroom experience that is likely familiar to most readers (Brooks and Brooks 1993, p.6-7). Most teachers (the trainers) use the teaching-as-telling approach (Goodlad 1984, Chapter 4) and rely heavily on textbooks. Harms and Yager (1981) found that over 90% of the science teachers use a textbook 95% of the time (described in Groves 1995). Given that science texts contain more new terminology than first year foreign language courses (Groves 1995), it is not surprising that students (the trainees) adopt a "mimetic" approach to learning, a process that involves students repeating, or miming, newly presented information on tests and quizzes (Brooks and Brooks 1993, p.15). Paulo Freire (1993, Chapter 2) called this the "banking model" of education. The teller-clerk teacher deposits knowledge into the students' heads and later withdraws it on tests.

Before I address this authoritarian form of education, I call into question the objectivist contention that one can objectively gather information from the environment. Our sense organs can only provide partial information about the environment. For example, what we see as a simple white flower, a bee sees as brilliantly patterned, because we cannot see the ultraviolet light that the bee can. Even among stimuli that we can perceive, our brain focuses on some information and selectively filters out other information. As Karl Popper pointed out: we never just look, we always look for something (Matthews 1994, p.228). As you sit there reading this document, you are unaware of the fabric of your clothing pressing against your skin (until now); our brain selectively filters out that information. Our brain then processes or constructs patterns from the information that passes through the filter. These constructs or conceptions empower and limit our understanding of the environment. As an example of a limiting construct, I perform a sleight-of-hand coin trick for my students. I appear to throw a coin from my right hand into my left. The coin "disappears" from my left hand and reappears when I pull the coin out of my ear with my right hand. Significantly, these constructs depend on our prior experience. I could not fool my two-year-old niece with my legerdemain; she had not learned that a vigorous forward motion of the hand means "throw." The delight in these tricks for the adult mind lies in the contradiction; intellectually, you know that the coin never leaves my right hand, yet the motion plays into a pattern learned and usefully applied. Most throwing motions do indeed result in objects being thrown.

The application for education is that students arrive, not as blank slates, but with a variety of conceptions and misconceptions (or naive conceptions) about how the world operates. These misconceptions can prove remarkably resistant to instruction (Gardner 1991). For example, graduating students of Harvard University were asked to explain why it is hotter in the summer and colder during the winter. Although all the students had studied this topic in their schooling, many offered an erroneous explanation--winters are colder because the Earth is farther from the sun (Perkins 1992, p.24). The correction explanation: in winter, the sun's rays must pass through more of the Earth's atmosphere because the Northern hemisphere is tilted away from the sun. One may criticize the student's lack of learning, but first one must acknowledge the usefulness of the students' naive conception--in situations on Earth, you get colder as you move away from a heating source.

With these ideas in mind, meaningful instruction should engage students actively in the learning process to determine and confront their prior conceptions. Howard Gardner has termed these confrontations, "Christopherian encounters" in honor of Christopher Columbus, "the first human being to demonstrate unequivocally to naive observers that the intuitive impression that the earth is flat had to yield to the alternate conception of the earth as spherical" (Gardner 1991, p.229). Students must be given experiences that highlight the inconsistencies of their naive conceptions. To arrange these experiences, teachers must understand student thinking on a topic. The implications of constructivist theory have led one science instructor to rethink "the portion of the time I spend telling students what I think versus the portion I spend asking them what they think" (Herron 1984, p.851). "The educator cannot start with knowledge already organized and proceed to ladle it out in doses... as an ideal the active process of organizing facts and ideas is an ever-present educational process" (Dewey 1938, p.82).

In their inquiry into student thinking, teachers can avoid the "correct answer compromise" in which students learn to mime answers to specific questions (Gardner 1991, p.141). The correct answer compromise is part of an efficiency model of education that allows rapid coverage of material. However, "trying to cover every important idea leads to the trivialization of them all" (Wiggins 1987, p.10). Inquiry-based teaching encourages students to construct their understanding in which new information is connected to previously understood concepts. Students come to a deeper understanding when they are allowed to discover the connectedness of knowledge. "To understand something is to know relationships. Knowledge is stored in clusters and organized into schemata that people use both to interpret familiar situations and to reason about new ones. Bits of information isolated from these structures are forgotten or become inaccessible to memory" (Resnick 1983, p.478). As John

Dewey admonished in *Experience and Education* (1938), "isolation in all forms is the thing to be avoided; connectedness is what we should strive for."

> ... there comes to mind the story told about John Dewey. There was a young man, it is said, who kept pestering John Dewey, asking: " What is the purpose of your philosophy?" ...finally, Dewey told the young man to sit down and when he did, he said: "The purpose of my philosophy is to climb a mountain."
>
> "To climb a mountain?" questioned the young man, somewhat surprised.
> "Yes, to climb a mountain."
> "And when you get to the top?"
> "You'll see another mountain." said John Dewey.
> "And then?"
> "You'll climb that," said Dewey.
> "And then?"
> "You'll see another mountain." said Dewey.
> "And then?"
> "You'll climb that," said Dewey.
> "And what will happen when there will be no more mountains?"
> "When you see no more mountains," said John Dewey, "it will be time to die."
>
> The whole purpose of school is to help children climb mountains, their own mountains. And the teacher should be there by their side to lend support, comfort, and encouragement while they struggle (Tenenbaum 1967, p.352).

The Learning Cycle

One pedagogical application of constructivist philosophy is the learning cycle. First developed for elementary science programs (Atkin and Karplus 1962), Edmund Marek and his colleagues at the University of Oklahoma (Marek et al. 1994b) have successfully extended the learning cycle for use in secondary and college science instruction. The process of instruction and learning includes cycles of exploration, concept invention (definition), and concept application (Karplus 1967, p.173).

Exploration - Most classes begin with a lab or an activity that encourages student exploration of ideas or phenomena. This phase fosters a "need to know" in the students. As they pursue and question observations, students wonder, "Why does this happen? What does this mean?" They begin looking for relationships between observations. The teacher acts as facilitator and guide--"principled understanding rarely arises as a result of unguided discovery" (Linn and Songer 1991, p.410). Rather than immediately answering students' questions, the teacher refocuses the students on their observations and encourages exchange among classmates. In this way, the class constructs a collective knowledge as students share their observations and hypotheses (Vygotsky 1978, p.163). Thus, students not only coordinate their thinking with their own observation, but also coordinate their thinking with that of other individuals through dialogue (Ziedler 1995). As Werner Heisenberg pointed out, "Science is rooted in conversations. The cooperation of different people may culminate in scientific results of the upmost importance" (Senge 1990, p.238). During this student-centered, exploratory phase, teachers can interact with students one-on-one to determine the conceptions and misconceptions that students bring to the classroom (Gardner 1991, p.85).

Invention - "To understand," as Piaget wrote in 1973, "is to invent" (Ginsburg and Opper 1988, p.260). The second phase involves a teacher-directed group discussion that leads to the concept invention. The term "invention" indicates that the learner invents the concept for him/herself. The teacher first brings out all observations and develops group consensus. All observations should be brought out--not only so that all students feel involved, but also the more observations that are brought out, the more likely that a pattern will emerge for the students. Too often, teachers move quickly to define a concept after eliciting one or two observations. With scant evidence, students have a difficult time distinguishing the theory from the observations that it explains. An exhaustive list of observations elicits the question from students, "how can we bring meaning and organization to what we have been experiencing and observing?" At this point, the teacher introduces related terminology and the name of the concept that accounts for the students' observations. Contrast this with more traditional instruction in which the teacher introduces terminology and the concept at the beginning of the lesson. Wiggins (1987, p.12) likened this teacher to "the boorish friend who wants to reveal how the mystery movie turns out before one has seen it."

Application - In the last phase, students apply the concept in a new context. This application allows the student to generalize the concept and connect it to other concepts within the student's mental framework. Students have multiple access to the concepts for later learning as connected concepts are more likely to be internalized and retained (Gardner 1991, p. 244). Students are empowered to learn as they can view education as effort-centered rather than ability-centered (Perkins 1992, p.61).

Collaborative Learning

> There is often a discrepancy between how science is practiced and how science is taught. When it is practiced, science often involves working collaboratively with colleagues while attempting to validate opposing hypotheses. Science education often involves reading a textbook, listening to lectures, and working by oneself.
>
> Johnson et al. 1985, p.207

Although collaborative learning activities have long been part of the repertoire of good teaching, there has been an upsurge of research into the effectiveness of collaborative learning since the 1970s. At that time, newly desegregated schools looked for techniques and approaches to improve race relations (Aronson et al. 1978, p.23). Research demonstrated that collaborative learning positively affected social relations (in particular, race relations), self-esteem and, as a result, educational achievement (Slavin 1987, p.1161). Collaborative learning changes the structure of the classroom from one expert and many listeners to many sources of information and greater interaction. As the Johnson quotation above suggests, collaboration in science class would also better match the practice of science. "Nearly all contemporary scientific research is done by teams of researchers working as a unit. The 12 most cited science research papers published in 1991 had an average of 6.6 authors per paper. A recent issue of *Science* carried research reports by author teams of 14, 17, and 27 individuals. The record is 134 authors for a study of world ecological imbalances" (Hurd 1995, p.7).

From a developmental perspective, Piaget suggested that social interaction facilitates cognitive development (Ginsburg and Opper 1988, p.219), specifically the transition from concrete to formal thinking (discussed on page 12). In positing a Zone of Proximal Development (ZPD), Vygotsky was more explicit about the role of collaborative activity in cognitive growth. Vygotsky (1978, p.86) defined the ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or *in collaboration with more capable peers*" (italics added). Collaborative activity promotes cognitive growth because children of similar ages are likely to be operating within one another's zone of development.

One example of a collaborative activity is the "jigsaw" method (Aronson et al. 1978) in which groups of students work on part of a task to be later presented to other classmates who work on other parts of the task. Specifically, the teacher divides the class into small groups of four to six students to study one subtopic (W, X, Y, or Z) of a larger topic. The small groups learn about their subtopic from the text, teacher, and other sources. The teacher reconfigures the students into groups of four such that each new group has one member from each of the first groups (W, X, Y, and Z). The students teach one another about their subtopics. In this way, students treat each other as resources; each student is an expert on his or her topic.

Gender Issues

Women continue to be underrepresented in science professions, constituting only 16 percent of all scientists and engineers employed in the United States (Davidson 1993). Furthermore, only 30% of college-bound high school women, compared to 50% of college-bound men, intend to study science (Mason and Kahle 1988, p.25). In a national survey research project *Shortchanging Girls, Shortchanging America*, the American Association of University Women (AAUW 1991) attributed this situation to barriers that women encounter in the process of science education, specifically in secondary school. Echoing a conclusion of the Carnegie Task Force Report (discussed on page 11), the AAUW says that experiences in secondary science classrooms critically affect students' attitudes toward science, more often adversely (also supported by Seymour 1995). The trend for most students, and for female students in particular, is an erosion of self-esteem. Comments such as, "I am not smart enough to learn science" were typical.

The Fall 1994 issue of *Independent School* was entitled "What Works for Girls." In it, the authors of several articles offered suggestions to educators wishing to make their classroom more "girl-friendly" including approaches discussed in the earlier sections of this chapter: collaboration, hands-on activities, and a clear connection between the abstract and the real (Brosnan 1994, p.23; Kruschwitz and Peter 1994; Allen et al. 1994). These authors emphasize that these approaches help create a better learning environment for boys as well.

Assessment/Evaluation

My approach to assessment and evaluation includes two major components: 1) a scientific portfolio and 2) tests.

First, students maintain a scientific journal and laboratory notebook. The notebook is a portfolio of student observations, interpretations, and reflections. Students organize their observations and interpretations from laboratory activities into formal presentations as laboratory reports and these reports are graded. These grades are not final. Portfolio assessment allows occasions for students to select from a body of work; to rethink, reconstruct, or revise their work; and to reflect over time upon the process of their learning (Beall 1994). In addition, this notebook includes journal entries for reflections on open-ended questions (see Extension Questions in Lesson Plans in Chapter 3). The students' reflections in their journals provide ongoing self- and course-assessment (Jacobs 1989, p.41).

Second, each unit will conclude with a test, consisting of a few objective, fact-related questions and subjective, process-related questions. These tests will be open-notebook and untimed. Untimed tests have become an institutional policy at my school (perhaps at most schools) for students that have demonstrated learning "disabilities" such as dyslexia or slow processing. I have extended this option to all my students.

Finally, I offer a comment on standardized tests. The frequently-heard comment from teachers--"I don't teach to the test"--indicates the contempt with which they hold most standardized tests. However, standardized tests remain society's educational gatekeepers (Hoerr 1994, p.31); so it is important that our students learn to do well on them. I believe that the challenging integrated curriculum described in this document will prepare our students to achieve on the subject area SAT-II tests. As Ted Sizer (1992, p.97) pointed out, students who are given "high expectations for using what they have learned--do better on traditional tests of presumed coverage. They seem to be in the habit of figuring things out."

Chapter 3 - The First Unit

This unit is intended for the start of the course. The eleven lessons reflect a constructivist perspective and use the learning cycle and collaborative learning. I begin most lessons with an activity or laboratory question that encourages student exploration. I act as a facilitator ("guide on the side"), rather than an explainer ("sage on the stage"). In lessons that begin with a discussion (Lessons 8 and 10), I elicit student observations and understandings on the topic before providing an organizational framework or defining the underlying the concept. Fensham et al. (1994, p.6) suggested a metaphor of the teacher 'parachuting in'. "This useful image distinguishes parachuting from 'free fall'... the teacher landing heavily on students' views, squashing them underground... To parachute is to drop lightly but effectively on the appropriate place at the appropriate time."

Goals of the Unit

In the first unit and, indeed in the first lesson, we raise two essential questions: What is science? and What is life? These questions will be answered tentatively at this point, and held in partial suspension to be revisited throughout the course, i.e., the students will NOT write down definitions for *science* and *life* to be memorized for a test. These topics of scientific method and characteristics of life are framed as questions rather than answers to match the spirit of inquiry that will pervade the course. We spend the first semester in the study of the human organism. This topic was chosen as an entree into the study of biology and chemistry because of its accessibility and inherent interest to ninth grade students. We begin our study of the human organism by focusing on the respiratory system. One characteristic of all living things is that they exchange of gases with the environment and large, multicellular organisms (such as humans) need a specialized respiratory surface such as the lung to efficiently exchange these gases. The unit concludes with a study of diffusion, the process by which gases are exchanged between the lung and the blood. In the second unit, we will examine the circulatory system, the system that transports gases between the lungs and all of the cells in the body.

Objectives of the Unit

At the end of this unit, the students should be able to:

1. Explain the role of observation in science.
2. Distinguish between observation and interpretation.
3. Discuss and relate the components of the scientific method.
4. List and explain the characteristics shared by all living things.
5. Explain the theme of the Unity of Life.
6. Explain the theme of the Diversity of Life.
7. Distinguish between quantitative and qualitative observations.

8. Establish the importance of scientific communication, specifically as it relates to the reproducibility of observations and consensus.

9. Distinguish between interpretation of observations and bias in observing.

10. Demonstrate the ability to use a microscope.

11. State and explain the cell theory (one characteristic of life).

12. Identify how technology expands our abilities to make observations.

13. Determine the response of humans to stress (exercise).

14. Explain the term "adaptation."

15. Identify factors that affect the respiratory rate of a goldfish.

16. Organize quantitative data on a table.

17. Graph quantitative data.

18. Interpret a graph of quantitative data.

19. Explain the meaning and importance of a controlled experiment.

20. Identify the gases in exhaled air.

21. Demonstrate the ability to use indicators to identify substances.

22. Identify the combustion products of a candle.

23. Compare the combustion products of a candle to the gases present in exhaled air.

24. Compare external, internal, and cellular respiration.

25. Identify the structures of the human respiratory system and state the function of each structure. (In particular, explain how the structure of the lung is related to its function.)

26. Trace the path of oxygen and carbon dioxide throughout the body.

27. Explain what gas pressure is and describe how it can be measured.

28. Apply Boyle's law to describe (qualitatively and quantitatively) how the volume of a gas is related to its pressure.

29. Describe how air enters and leaves the lung.

30. Explain the process of diffusion.

The Lessons

Lesson 1	What is science? What is life?
Lesson 2	Comparison of living things: a pillbug and your laboratory partner.
Lesson 3	Introduction to the microscope: The Cell Theory.
Lesson 4	Humans, at rest and after exercise: Introduction to human biology unit.
Lesson 5	The respiratory rate of a goldfish.
Lesson 6	Identification of gases in inhaled and exhaled air.
Lesson 7	Identification of combustion products of a candle.
Lesson 8	Descriptive introduction to the function and structure of the human respiratory system.
Lesson 9	Boyle's law.
Lesson 10	Detailed description to the function and structure of the human respiratory system.
Lesson 11	Diffusion.

Comparison of Objectives and Lessons

The following chart indicates when each objective is addressed in the lesson sequence. The objectives are generally covered in sequential order as the lessons progress. Some objectives are revisited in sequential classes (5, 12, and 19), and objective 25 is revisited two lessons later.

The Lessons

Objectives	1	2	3	4	5	6	7	8	9	10	11
1	x										
2	x										
3	x										
4	x										
5	x	x									
6		x									
7		x									
8		x									
9		x									
10			x								
11			x								
12			x	x							
13				x							
14				x							
15					x						
16					x						
17					x						
18					x						
19					x	x					
20						x					
21						x					
22							x				
23							x				
24								x			
25								x		x	
26								x			
27									x		
28									x		
29										x	
30											x

Lesson 1

Topic: What is science? What is life?

Objectives: At the end of this lesson, students should be able to:

1. Explain the role of observation in science.
2. Distinguish between observation and interpretation.
3. Discuss and relate the components of the scientific method.
4. List and explain the characteristics shared by all living things.
5. Explain the theme of the Unity of Life.

Teacher Preparation:

Part A: Determine a seating chart based on the students' first names in alphabetical order and write it on the overhead, listed by *last* names.

Part B: Place a drop of mercury in a petri dish and add enough water to cover the mercury. Add several drops of concentrated nitric acid. Place a few grams of potassium dichromate in a beaker labeled "food" (Talesnick 1984, p.122).

Procedure:

Part A: As the students enter the room for the first class, point out the seating chart on the overhead. Students must determine the "theory" by which seats were assigned. Encourage the students to share observations about themselves and make preliminary explanations.

Students usually determine an explanation for the seating chart within a few minutes. Do not confirm that the students have arrived at the "right" (i.e., the teacher's) theory. In science, testing supports a theory, not some higher authority. In addition, point out that useful theories account for all relevant observations, regardless of whether their theory matches the teacher's theory. In this exercise, the students have essentially performed the scientific method; they have looked for relationships between observations, and they have made and tested explanations for these relationships. Emphasize the dynamic interplay among the activities of the scientific method (as opposed to the static linearity described in the first chapter of most science textbooks). The terms "hypothesis," "experiment," and "theory" can be introduced here. The unique feature of science--testibility--can also be discussed. An added benefit: they learn each other's first name. Students enter the ninth grade at my school from over 30 different middle/elementary schools. More information can be gathered on a questionnaire to generate increasingly challenging seating charts. This activity provides a good transition as the students are settling in during the first few minutes of class.

Part B: Place the petri dish containing the mercury droplet on the overhead projector. If necessary, mask the dish so that it cannot be directly seen by the students. Turn the projector on. Sprinkle a few crystals of potassium dichromate (the "food") near the mercury droplet and it will start to move around. (If this does not happen, add a few more drops of nitric acid.) As students observe the "critter," ask the following questions: What is biology? What is life? What are the signs of life? Have the students write answers to these questions in their lab notebooks. Encourage student discussion in pairs or in small groups. Pull the class together and list their characteristics of life on the board. Have one student act as scribe.

The students will come up with a fairly complete list of the characteristics of life (usually covered in the second chapter of any biology textbook). Distinguish those items that are direct observations (for example, movement) and those that involve inference or interpretation (respiration or breathing). Go back over each item on the list and consider the following questions: Do all living things perform all these activities and/or characteristics? For example, do plants move? Can non-living things do any of (or all of) these? Introduce the theme of the Unity of Life. Reveal to the students in *as gentle manner as possible* that they have been observing mercury, not something living. ("Ha, ha, you're stupid" is not the recommended response.) Discuss the difficulty in defining life, particularly at the "boundaries." Since we cannot directly observe them, microscopic organisms are less familiar to us. This activity can be termed a "Christopherian encounter" (described on page 18). Students usually believe that the mercury was alive because they operate on the naive conception that movement indicates life. In confronting this misconception, we can discuss other non-living things that move such as clocks. Most students understand that clocks are not alive, so we can further refine their misconception--it was the *erratic* movement of the mercury that led students to believe the mercury blob was alive. The students will return to their list of life's characteristics repeatedly throughout the course.

Extension: What "strategies" did the students use to solve the seating chart? Were the students completely "objective" in their thinking? Would it have been possible to solve the seating chart while being completely objective? Why did the students think that the mercury was alive? These questions encourage students to think about their thinking, also called metacognition (Kuhn et al. 1988, p.6; Perkins 1992, p.100).

Homework: Students read Chapter 1 in the *Heath Biology* (McLaren et al. 1991) and respond in their scientific journals to the extension questions.

Lesson 2

Topic: Comparison of living things: a pillbug and your laboratory partner.

Objectives: At the end of this lesson, students should be able to:

5. Explain the theme of the Unity of Life (from Lesson 1).

6. Explain the theme of the Diversity of Life.

7. Distinguish between quantitative and qualitative observations.

8. Establish the importance of scientific communication, specifically as it relates to the reproducibility of observations and consensus.

9. Distinguish between interpretation of observations and bias in observing.

Teacher Preparation: Make available: pillbugs (*Isopods*), dissecting microscopes (10X-30X) or hand magnifying lenses, butcher paper, marking pens, and tape.

Procedure: In an activity similar to Part B of Lesson 1, pairs of students (lab teams) observe a pillbug and observe their partner. To better observe the pillbug, students can use the dissecting microscopes or a hand lens. Students write observations in their lab notebooks. Encourage lab teams to share their observations with other teams. One approach: one member of a lab team joins with another member from a different lab team and compares observations in a modified "jigsaw" approach (discussed on page 24). Students should consider the similarities and the differences between their partner and the pillbug. (Teachers need to monitor this activity for unacceptable humor and disparaging "observations.") Have each lab team trade lab notebooks with another team and draw the described organisms (partner and pillbug) on butcher paper. The drawings should be based *strictly on the observations written down*. Post the drawings around the room. Read aloud the description on which a drawing is based.

Students are likely to be better at describing and distinguishing their lab partner than they are at describing the pillbug. Discuss bias in scientific observations, and the influence of experience (i.e., students have more experience observing humans than pillbugs.) In addressing the question--What characteristics are shared by pillbugs and humans?--reinforce the theme of the unity of life discussed in the first lesson. Briefly introduce the theme of the diversity of life--organisms find different solutions to similar problems; for example, pillbugs solve the problem of locomotion with many legs, while humans do so with two. We discuss this theme in greater detail in the second semester (see top half of page 9, topic J).

Extension: Some pillbugs may appear dead or may be, in fact, dead. How can one distinguish something that is dead from something that was never alive? (This is a sophisticated question. The next lesson begins to answer this question and it will be revisited later in the course.)

Homework: Students read Chapter 2 in the *Heath Biology* (McLaren et al. 1991) and respond in their scientific journals to the extension question.

Lesson 3

Topic: Introduction to the microscope: The Cell Theory.

Objectives: At the end of this lesson, students should be able to:

10. Demonstrate the ability to use a microscope.

11. State and explain the cell theory (one characteristic of life).

12. Identify how technology expands our abilities to make observations.

Teacher Preparation: Make available: microscopes, lens paper, microscope slides, cover slips, newspaper, toothpicks, aquatic plants (*Elodea*), onions, stains, small beakers, and droppers.

Procedure: Demonstrate the care and use of a microscope. Demonstrate the techniques of making a wet mount slide and staining a microscope slide preparation. Discuss the approach to making biological drawings. Students begin by looking at newspaper print to acquaint themselves with the use of a microscope. Students examine a variety of living tissues--cheek cells, *Elodea*, and onion skin--and make drawings in their lab notebooks. Students may suggest other tissues. Encourage student discussion and comparison of drawings and slide preparations.

In the follow-up discussion, refer to extension question from Lesson 2. The presence of cells would distinguish something that was dead from something that was never alive.

Discuss how the microscope is a tool that expands our ability to make observations. In a broader sense, tools act "as amplifiers of human capacities and implementors of human activity" (Bruner 1966, p.81). Post student drawings around the classroom.

Homework: In their science journals, students write an educational autobiography (Countryman 1993, p.60). Stimulate their thought processes with the following questions; How do you learn best? What situations make it difficult for you to learn?

Lesson 4

Topic: Humans, at rest and after exercise: Introduction to human biology unit.

Objectives: At the end of this lesson, students should be able to:

12. Identify how technology expands our abilities to make observations (from Lesson 3).

13. Determine the response of humans to stress (exercise).

14. Explain the term adaptation.

Teacher Preparation: Make available the following equipment: stethoscope, blood pressure cuff, respirometer, and electrocardiogram (ECG).

Procedure: Students observe their lab partners at rest, and after two minutes of vigorous exercise. Students write their observations in their lab notebooks. Encourage lab teams to share their observations. Some students may ask to use a stethoscope and a blood pressure cuff. Pull the class together and list observations on the board. Have one student act as scribe. Discuss how humans respond or adapt to the stress of exercise. Do humans respond to other stresses in a similar fashion?

Examples of observations that might be made after exercise include: increased breathing rate, increased heart rate, flushing, and sweating. Some students will have made quantitative observations, for example, the number of breaths in one minute. Discuss the importance of using units; a number without a unit is meaningless. Compare qualitative and quantitative observations and discuss situations when each is useful. For example, if your blood pressure is "fine" or within an acceptable range, you may not need to know the exact systolic and diastolic readings. However, if your blood pressure is too high, you may need to monitor it as you modify your diet and exercise regime. Like the microscope, discuss how the stethoscope and the blood pressure cuff are tools that expand our ability to make observations. Indicate that the word "observation" can refer to senses other than visual, as it did with the stethoscope.

Other equipment such as the respirator and the ECG can be introduced here if there is time. Otherwise, the students will use this equipment in the second unit on the Circulatory System. For the rest of this unit, we will focus on the Respiratory System.

Extension: Can students think of other examples of technology expanding our abilities of observation?

Homework: Students respond in their scientific journals to the extension question.

Lesson 5

Topic: The respiratory rate of a goldfish.

Objectives: At the end of this lesson, students should be able to:

15. Identify factors that affect the respiratory rate of a goldfish.

16. Organize quantitative data on a table.

17. Graph quantitative data.

18. Interpret a graph of quantitative data.

19. Explain the meaning and importance of a controlled experiment.

Teacher Preparation: Separate goldfish into 400 ml beakers containing aquarium water. Make available: thermometers and graph paper.

Procedure: Students begin by observing a goldfish at rest. What indicates that a goldfish is "breathing"? What other behaviors are noticed? In the last lesson, students examined the effect of stress (exercise) on the respiratory rate of a human. Discuss the question--What factors might affect the respiratory rate of a goldfish? Encourage students to develop experiments to test those factors.

One factor that can be tested is temperature of the surrounding environment (McLaren et al. 1991, p.537). Divide the students interested in testing temperature into two groups; one group will test the response of their fish to colder temperatures, while the other will test the response to warmer temperatures. For the warm water group, place some aquarium water in a large beaker on a hot plate. Water from this beaker can be added *slowly* to increase the temperature of the water in the beaker containing their fish. For the cold water group, place some aquarium water in a large beaker with ice cubes. This water can be used to slowly decrease the water temperature surrounding their fish. After every change of a few degrees, students count the number of breaths that the fish makes in one minute. The goldfish should not be harmed if the water temperature is changed slowly and kept between 10°C and 45°C. Students write their observations in their lab notebooks. (Discuss the usefulness of recording quantitative data in the form of tables.) Encourage students to share observations. Write the class data on the board.

Students that tested other factors share their results with their classmates. All students graph the respiratory rate of a goldfish vs. the water temperature. Discuss the graph.

The activities in the first four lessons were observational activities. In this lesson, students performed a controlled experiment. Discuss the meaning and important of a control in an experiment.

Extension: What is the meaning of the word "controlled" in a controlled experiment? Can students describe another controlled experiment?

Homework: Students respond in their scientific journals to the two extension questions.

Lesson 6

Topic: Identification of gases in inhaled and exhaled air.

Objectives: At the end of this lesson, students should be able to:

19. Explain the meaning and importance of a controlled experiment (from Lesson 5).

20. Identify the gases in exhaled air.

21. Demonstrate the ability to use indicators to identify substances.

Teacher Preparation: Prepare a dilute solution of Brom Thymol Blue (BTB). Distribute cobalt chloride paper. Make available the following liquids: vegetable oil, 100% alcohol, and water. Make available tanks of the following gases: carbon dioxide, oxygen, and nitrogen.

Procedure:

Part A: Students explore the following question--What materials (liquids and/or gases listed above) make cobalt chloride paper and BTB solution change colors? Students answer this question in their lab notebooks. Encourage student discussion in pairs or in small groups.

Pull the class together and briefly discuss the meaning of the word "indicator." (An indicator is a tool for identifying the presence of a specific substance. Cobalt chloride paper indicates the presence of water by turning blue to pink. BTB indicates carbon dioxide by turning from blue to yellow.) These indicators will be used in Part B as well as in later lab exercises.

Part B: Encourage students to discuss methods for using cobalt chloride paper and BTB solution to compare inhaled and exhaled air. One possible procedure for students to follow: in a testtube labeled "I" (for inhaled air; i.e., air in the atmosphere), add a piece of cobalt chloride paper, stopper the tube, and shake. Note color change. In a testtube labeled "E" (for exhaled air), add a piece of cobalt chloride paper, *breathe into the tube*, stopper the tube, and shake. Note color change. Repeat these steps, using two squirts of BTB in place of cobalt chloride paper. Students record all observations in the lab notebook.

List student observations on the board. Emphasize that an observation of "color change" should specifically include the initial and the final color. As a result of these procedures, students should "discover" that exhaled air contains more carbon dioxide and water vapor than inhaled air. They probably "knew" this before, however, now they have direct observations to support (emphasize that they did NOT "prove") their knowledge.

Students can examine whether other organisms give off carbon dioxide. Add BTB solution to a testtube. Wedge a cotton ball into the testtube so that it rests just above the BTB solution. The cotton ball will provide a platform for whatever small animal is used: pillbug, mealworms, crickets, etc. Stopper the tubes and let sit for 24 to 48 hours.

Extension: What does it mean "to know" something? Can one prove that carbon dioxide is present in exhaled air? What results in this lab exercise might disprove it? For example, is carbon dioxide the only substance that changes the color of BTB solution? (In fact, no--carbon dioxide forms a weak acid in aqueous solutions; any acid changes the color of BTB solution.)

Homework: Students respond in their scientific journals to these extension questions.

Lesson 7

Topic: Identification of the combustion products of a candle.

Objectives: At the end of this lesson, students should be able to:

22. Identify the combustion products of a candle.

23. Compare the combustion products of a candle to the gases present in exhaled air.

Teacher Preparation: Make available: cobalt chloride paper, BTB solution, candles, matches, and beakers.

Procedure: Encourage students to develop an experiment to determine the products of a burning candle using the indicators from the last lesson (cobalt chloride and BTB solution). A possible procedure: cover a burning candle with a beaker until the flame goes out. Why? Notice the condensation of the inner surface of the beaker. Use cobalt chloride paper to determine if this is water vapor. Relight the candle and again cover it with a beaker until it goes out. Turn the beaker upright and quickly pour in BTB solution and swirl.

As time allows, students can identify the combustion products of other materials: methane gas (Bent 1986), paper, a peanut, etc. Alternatively, these identifications can be done as teacher demonstrations. Combustion of all these materials yields carbon dioxide and water vapor.

Extension: How do the combustion products of a candle compare to the gases present in exhaled air in Lesson 6? What is the significance of this comparison? What produced the carbon dioxide present in exhaled air?

Homework: Students respond in their scientific journals to the extension questions.

Lesson 8

Topic: Descriptive introduction to the structure and function of the human respiratory system.

Objectives: At the end of this lesson, students should be able to:

24. Compare external, internal, and cellular respiration.
25. Identify the structures of the human respiratory system and state the function of each structure.
26. Trace the path of oxygen and carbon dioxide throughout the body.

Teacher Preparation: Set up the multi-media program *A.D.A.M. Essentials* (Broderbund Software), a CD-ROM on human anatomy.

Procedure: In discussion, elicit students' beliefs on the need for respiration. Build on their conceptions, or confront their misconceptions (Gardner 1991, p.229; Linn and Songer 1991, p.403; Resnick 1983, p.478) to introduce the functions of the human respiratory system. Compare breathing, external respiration, internal respiration, and cellular respiration. In addition, elicit students' understanding of the structures of the human respiratory system. Demonstrate the respiratory system on *A.D.A.M.* (Students will use this multimedia program throughout the units on human biology.) Allow students to explore *A.D.A.M.*

Homework: Students read p.648-652 in *Heath Biology* (McLaren et al. 1991). Spend at least 15 minutes exploring the respiratory system on *A.D.A.M.* on the library computers.

Lesson 9

Topic: Boyle's law.

Objectives: At the end of this lesson, students should be able to:

27. Explain what gas pressure is and describe how it can be measured.

28. Apply Boyle's law to describe (qualitatively and quantitatively) how the volume of a gas is related to its pressure.

Teacher Preparation: Make available: 60 ml plastic syringes with plunger and end cap, large rubber one-hole stoppers, ring stands, clamps, and weights.

Procedure: Students explore the syringes. Discuss the question--why it so hard to push in or pull out the plunger when the end cap is secured? Develop a qualitative understanding of the relationship between pressure and volume of a gas (they are inversely related--as pressure increases, the volumes decreases).

Students break into their lab teams to develop a method to answer the question--what is the quantitative relationship between pressure and volume of a gas? A possible procedure: set the plunger at its highest marking on the cylinder. Fasten the end cap onto the end of the syringe and insert into the rubber stopper. Clamp the syringe-stopper apparatus in an upright position. Systematically add weights on top of the plunger and measure the volume of the trapped air. Graph pressure versus volume.

Encourage students to consider other ways of graphing pressure and volume. Attempt to get a straight line. (Graphing pressure (P) vs. the inverse of the volume (1/V) yields a straight line.) Discuss quantitative interpretations of the graphs while recalling the students' qualitative understanding of the relationship between the pressure and volume of a gas. Lead students to "discover" the existence of atmospheric pressure. Begin with the question--if no pressure is exerted on a gas, what would be its resulting volume? (The answer is infinity; the gas would continue to expand under conditions of zero pressure.) Why does the graph of P vs. 1/V *not* pass through the origin (0,0)? That is, when the pressure equals zero (i.e., there are no weights on the plunger), why is 1/V *not* equal to zero (i.e., why does the volume *not* equal infinity?) At this point, students might suggest that atmospheric pressure prevents the infinite expansion of the trapped air. Perform demonstrations of atmospheric pressure; two that are commonly listed in teacher resource books are *Egg-in-the-bottle* and *Collapsing can.* Brief procedures are listed below:

Egg-in-the-bottle - Heat up a small amount of water in a large flask over a Bunsen burner. The opening of the flask should be just smaller than a peeled hard-boiled egg. After the water is boiling, set the flask on the counter and place the egg over the opening of the flask. The atmospheric pressure will force the egg into the flask as the water vapor inside the flask condenses, i.e., the gas pressure inside the flask decreases. Make a subtle point--Does atmospheric pressure push the egg in or, is the egg sucked in? The more accurate explanation is that the egg was pushed in by atmospheric pressure. Suggestion: leave the egg-in-the-bottle out on the front bench at the beginning of class before the demonstration. Ask the students to figure out how the egg was put into the bottle.

Collapsing can - Holding it with tongs, heat up a small amount of water in an aluminum soda can over a Bunsen burner. After the water is boiling, invert the can into a large pail of the water. The atmospheric pressure will instantaneously collapse the can when the water vapor inside the can condenses, i.e., the gas pressure inside the can decreases.

Extension: How might Boyle's law relate to the mechanism of breathing? Does air get pushed into or sucked into our lungs?

Homework: Students read p.213-215 in *Heath Chemistry* (Herron et al. 1993) and respond in their scientific journals to the extension question.

Lesson 10

Topic: Detailed discussion of the function and structure of the human respiratory system.

Objectives: At the end of this lesson, students should be able to:

25. Explain how the structure of the lung is related to its structure (recall Lesson 8).

29. Describe how air enters and leaves the lung.

Teacher Preparation: Make available: 2-liter clear-plastic soda bottles, Y-tubes, balloons, large one-hole rubber stoppers, sealer (wax, clay), rubber bands, cotton balls, baggies, and a large rubber sheet (or large balloons).

Procedure: Challenge the students to construct a model of the chest using the materials listed above. One possible procedure for students to follow: cut off the bottom of the soda bottle (representing the thoracic cavity). Insert a glass Y-tube (representing the trachea and bronchi) through a one-hole rubber stopper that fits into the mouth of the soda bottle. Use sealer if the stopper does not fit tightly. Fasten two balloons (representing the lungs) to the two arms of the Y-tube with rubber bands. Use another rubber band to secure a circle of rubber sheeting (representing the diaphragm) over the bottom of the soda bottle (Morholt and Brandwein 1986, p.320). Observe how gases move into and out of their "lungs" when the "diaphragm" is pulled down. In discussion, relate Boyle's law to the mechanism of breathing. Review the function and structures of the human respiratory system, particularly focusing on the lung. Discuss the questions--How is this model an accurate representation of the thoracic cavity?

How is it inaccurate? (The balloons do not accurately reflect the millions of tiny sacs, called alveoli, present in human lungs.)

The effects of smoking can be demonstrated by placing cotton balls inside the lungs of the chest model. Insert a lit cigarette into the tube that represents the mouth of the model. After a few inflations, the cotton balls become quite stained. This effect can be seen more easily if clear plastic baggies are used instead of balloons for the lungs.

In discussion, pose the following questions--Once oxygen has entered the lungs, how does it get to the rest of the body? Where does the exhaled carbon dioxide come from? (These questions can be used as Extension Questions.) Most students will know that the circulatory system (the topic of the next Unit, see page 9) is involved. Follow-up question--How does oxygen move from the lung to the blood? Introduce the concept of diffusion (the topic of the next lesson).

Homework: Students read p.652-655 in *Heath Biology* (McLaren et al. 1991). In their scientific journals, students outline the concepts investigated in this unit.

Lesson 11

Topic: Diffusion.

Objectives: At the end of this lesson, students should be able to:

30. Explain the process of diffusion.

Teacher Preparation: Make available: ammonia, potassium permanganate crystals, and beakers. Set up the kinetic molecular demonstrator on the overhead.

Procedure: Students explore the diffusion of different substances in different media: diffusion of methane and ammonia in air, diffusion of potassium permanganate (a purple crystal) in water, and diffusion of carbon dioxide from air to water (Marek et al. 1994a, p.74).

Students can examine the effect of different factors on the rate of diffusion. In observing the diffusion of potassium permanganate, different media may be tried, or the temperature of the media may be changed.

Discuss the concept of diffusion--particles move randomly from an area of greater concentration to lesser concentration until evenly distributed. Highlight the discussion with the use of the kinetic molecular demonstrator on the overhead. Reinforce the idea that diffusion accounts for the exchange of gases between the lungs and the blood.

Review the major concepts investigated in this unit in preparation for the assessment that will occur in the next lesson.

Extension: Make a wet mount of *Elodea* (see Lesson 3). Place several drops of concentrated salt solution along one side of the cover slip. Place the edge of a paper towel along the opposite side of the cover slip. As the towel soaks up water, the salt solution will be drawn under the coverslip. What happens to the *Elodea* cells in this highly saline environment? Repeat procedures, but use distilled water in place of concentrated salt solution. What happens to the *Elodea* cells in the presence of distilled water?

Repeat the entire sets of procedures using cheek cells in place of *Elodea*. You must be looking at the cheek cells through the microscope as you add the distilled water.

Homework: Study for assessment.

Chapter 4 - Implementation

In a chapter in the book *Interdisciplinary Curriculum* (ed. Jacobs 1989), David Ackerman provides a framework for educators pondering curriculum integration. He describes two sets of criteria, the intellectual and the practical. Ackerman's framework echoes Michael Fullan's terminology in his discussion of the *what* and *how* of educational change (Fullan 1991). I explained the intellectual criteria (the *what*) for an integrated biology and chemistry curriculum in Chapters 1 & 2. In this chapter, I will discuss the practical criteria (the *how*) of implementing this curriculum at my school in San Francisco, University High School (UHS).

I will set the stage with a brief discussion of UHS. Next, I will describe the steps that have already been taken and the plans for the future by the science department at UHS. This chapter culminates in some recommendations for other schools considering curriculum integration or, indeed, any curriculum change.

Background on University High School

UHS is a small (400 students) independent high school located in the affluent Pacific Heights area of San Francisco. The school occupies a Julia Morgan-designed building constructed at the turn of the century. Considered among the best academic private schools in the Bay Area, UHS receives five times as many applications as it has spaces available in the ninth grade class. As its name implies, UHS sends virtually all of its graduates to four-year colleges and universities.

Despite its location and selectivity, UHS offers much to belie the stereotype of an elite private school. The school maintains a strong financial aid program. Twenty-two percent of the student body receives financial assistance totaling $675,000 (out of an operating budget of 5.5 million dollars). In addition, UHS "seeks to be a school not only in the city, but of the city." To this end, the school developed a community service learning program to facilitate contribution of the students to the broader community. The school employs two three-quarter time Community Service Learning Directors who, with the student-run Community Service Learning Committee, helps place students in positions with nonprofit agencies. Each student must complete twenty hours of independent community service each year. In addition, all students participate in a class project that enables them to work for service organizations such as day care centers, hospitals, and convalescent homes. The school schedule includes a weekly 95-minute block for students to perform community service.

UHS also maintains an ethos of caring and support within the walls of the school. In its mission statement, the school professes a commitment to the "welfare and development of the total student." The students are allowed to discover different definitions of "excellence" in many co-curricular activities. In addition to a strong athletic program, the school supports an outdoor education program, a People of Color support group (student requested and organized), a Gay and Lesbian support group (ditto), and Summerbridge, a six-week academic program for middle school students taught by high school students. Other support structures for students include a school counselor, a health educator, a college counselor, a peer advising program (non-academic), and a peer tutoring program (academic). However, the primary system of guidance and support for students is the Advising program. Each faculty member meets weekly with 10 student advisees.

The faculty (60 members) is seen as a strength of the school, generally praised by all components of the school community; students, parents, administration, and the board of trustees. The faculty is educated and experienced; over 75% hold advanced degrees in their academic field and most have taught elsewhere before coming to UHS. Beyond their teaching responsibilities, faculty members serve on committees that assist the administrative council in overseeing the day-to-day operations. The administrative council includes the Headmaster, the Academic Dean, the Dean of Students, the Chief Financial Officer, the College Counselor, the Development Director, and the Admissions Director.

This laudatory introduction to UHS serves to highlight; 1) the strong academic program, 2) the strong faculty (the two go hand in hand), and 3) the institutionally supported care and concern for the students. This care and commitment can lead to conflicting priorities when attempting curricular or systemic change.

Curricular Change

During 1992-1993, the Science Department decided to consider integrated science courses. This decision evolved out of pie-in-the-sky discussions, "if we could change everything, what would we do?" In the spring of 1993, the four biology and chemistry teachers (Ray Boyington, Ann Pogrel, Rob Spivack, and I) met away from school for a day to explore the feasibility of an integrated biology and chemistry course. The physics teachers expressed no interest in changing their course. (A practical consideration: the four biology and chemistry teachers had no experience teaching physics and the two physics teachers had no experience teaching either biology or chemistry.) After a broad ranging discussion, we decided that an integrated course would not compromise the integrity of either discipline and, additionally, would be a better educational experience for our students (see Rationale on pages 5-8). Based on this skeleton plan, the administration agreed to support us with Professional Development Funds for two weeks during the summer of 1993 to "flesh out" a curriculum for an integrated biology and chemistry course.

Simultaneously, three other significant changes were being considered at UHS: 1) The Community Service Learning Committee was redefining its focus and pondering greater integration into the academic curriculum. 2) A Schedule Committee was formed and charged, among other priorities, to find more time for science labs. 3) The English, History, and Arts teachers were considering greater integration and/or coordination of their instruction of ninth and tenth grade students. Collectively, these impending changes raised the intoxicating possibility that we might develop a coordinated and/or integrated curriculum across all disciplines for the lower division (ninth and tenth grades). I will return to these changes later in this section. I will focus now on the changes in the science department.

As science department chair, my role was to lead our meetings and to facilitate communication between the department and the administration. In addition, I wrote the application for official University of California (UC) approval of our integrated curriculum (see Appendix). As I indicated earlier, UHS sends 30%-40% of its graduates to a UC school. The Academic Dean, William Bullard, aided me in this task. UC granted approval for the Integrated Biology and Chemistry Curriculum in January 1995.

Four science teachers (Ray Boyington, Ann Pogrel, Rob Spivack, and I) met for two weeks over the summer of 1993 and developed an integrated biology and chemistry curriculum for all ninth and tenth grade students. I had researched information on science reform published by national and state science organization--specifically, *Science for All Americans* (American Association for the Advancement of Science 1989), the *The Content Core: A Guide to Curriculum Designers: Scope, Sequence, and Coordination* (National Science Teachers Association 1993), *Fulfilling the Promise: Biology Education in the Nation's Schools* (National Research Council 1990), and the *Science Framework for California Public Schools* (California State Board of Education 1990). However, we drew primarily on our teaching experience to develop our curriculum. With 12 years of teaching, I had the *least* experience of the group. Our resulting curriculum (listed on page 9) incorporated many suggestions by the national and state organizations, although we had not explicitly referred to them.

These organizations have published additional reports in the last two years. All recommended interdisciplinary and/or multidisciplinary approaches to science education as well as emphasis on the "habits of mind" questions (for example, "how do we know?") and active learning environments. Titles of publications are listed in italics.

American Association for the Advancement of Science (AAAS) - Project 2061
Benchmarks for Science Literacy (1993)
Biological Sciences Curriculum Study (BSCS)
Developing Biological Literacy (1993)
Redesigning the Science Curriculum (1995)
National Research Council (NRC)
National Science Education Standards (1995)
National Science Teachers Association (NSTA)
Scope, Sequence & Coordination (SS&C) of National Science Education Content Standards (1994)
The Content Core - A Guide for Curriculum Designers (1994)
A High School Framework for National Science Education Standards (1995)

We chose three short-range goals. First, our separate biology and chemistry courses in 1993-1994 were used as testing grounds for the topic order of the integrated curriculum. Based on that experience, we revised the biology and chemistry courses slightly for 1994-1995. Second, we provided training for Ray Boyington and Rob Spivack. Ray has been dedicated to teaching chemistry, while Rob had only taught biology. Ann Pogrel and I have taught both biology and chemistry courses. Ray and Rob are presently (1994-1995) co-teaching both a chemistry and a biology class. The administration supported this training by reducing their course loads by 1/2 class. Third, I further researched issues in integrating science curriculum in project supported by the Klingenstein Center at Teachers College

Columbia University for 1994-1995 school year. Specifically, I have been investigating integrated science courses at other high schools, cognitive development in adolescents, the history of reform in science education, and educational philosophy.

Our long-range goal is to implement the first year of the integrated curriculum for ninth grade students during the 1995-1996 school year. This step will coincide with implementation of other systemic changes occurring at UHS, including the new schedule. The four science teachers will meet during the last two weeks of June 1995 for final planning, again supported by Professional Development Funds. In addition, the four science teachers will meet weekly throughout 1995-1996 as the newly formed Integrated Science Committee. Each of us will teach our own section(s) of the integrated course, *i.e.*, no team-teaching. Chemistry will continue to be offered in 1995-1996 for the students who took biology in 1994-1995. Full implementation of the integrated science program for both ninth and tenth grade students will occur in 1996-1997.

I return to the three other significant changes under development at UHS. The Community Service Learning Committee has spent the last two years redefining its focus. They have been somewhat successful at greater integration into the academic curriculum. Rather than systemic integration, they have taken a course-by-course approach. Specific teachers have developed partnerships with the Community Service Learning Office. For example, one Spanish teacher committed class time to training his students to act as English tutors for recently-emigrated Latinos. It is hoped that these partnerships will provide models for other teachers to emulate.

This Schedule Committee spent last year (1993-1994) considering the schedules of other schools and trying to develop new schedules. Besides its charge to find more time for science labs, the Committee was constrained by the following: other disciplines did not want to decrease their classtime, the Community Service block could not be shortened (ideally extended), a common lunch must be maintained for student club and activities meetings, and after-school athletics limited any extension of the end of the school day. Even given these limitations, the committee came up with three models for faculty consideration. (This year--1994-1995--has been spent discussing these models.) This issue has been met with a tremendous amount of resistance. Some protest the "inequity," maintaining that science classes should not have any more time than other disciplines. Others simply resist change, claiming that the present schedule suits them fine. In early April 1995, the Headmaster Peter Esty chose a new schedule to take effect in 1995-1996 that adds 25 minutes to the science laboratory blocks. They will now total 95 minutes.

All of the English, History, and Arts teachers met last year to consider greater integration and/or coordination of their instruction of ninth and tenth grade students. Their efforts have not progressed smoothly. They have selected some common readings and hope to underscore thematic material in all of their courses. However, the large group size, the large domain to be integrated, and some strong-willed participants have all conspired to limit comprehensive integration. Some pathways of communication have been opened and progress is continuing.

General Comments

In comparison to the humanities deliberations, the science department has had relatively placid meetings. Some reasons I alluded to in the last section. Our group was smaller--four science teachers vs. twelve humanities teachers. Our task was smaller--integration of two areas within a discipline vs. integration across several disciplines. Lastly, the science department has been one of the more cohesive departments at UHS. Our limited physical space has contributed to this cohesiveness. The science teachers all have their desks in one large office. In this regard, our meetings could extend beyond the formal meeting times, as discussions often arise spontaneously during free time. Informal or off-task interactions (nerf ping pong, juggling, etc.) have contributed to the community feel of the science office and enhanced working relationships. We also share classroom space and have a tiny preparatory room to setup labs. Thus, we are often in each other's classrooms, making up solutions and getting out equipment. I find that I learn a great deal from my colleagues about teaching in this short time. Lastly, the department members have demonstrated an impressive pedagogical flexibility in addition to (some would say "despite") their vast experience teaching experience.

In the article that I discussed at the beginning of this chapter, David Ackerman (1989, p.31) identified three practical considerations for curricular change: time, schedule, and budget.

Time is required for curricular development and evolution. In the planning stages, we needed concentrated time away from school, when our attention was not split by the daily demands of teaching. Constructivist philosophy applies to teachers as well as students, teachers must be given the time and support to construct their understanding of an educational change based on their prior teaching history. Next year, when the new curriculum is implemented, we have planned weekly meetings for communication and coordination.

The schedule is destiny. This statement does not overstate the impact that the schedule can have in implementing educational and curricular decisions. Students must have time to reflect upon and process the overarching concepts taught in an integrated curriculum. Longer blocks of time must be carved out of the schedule for a more student-centered, hands-on approach. Time also needs to be allocated for teacher collaboration and consultation.

The success of addressing the foregoing two factors depends on the institutional willingness to commit money. The budget must support the training of teachers and the acquisition of additional materials. This support must continue beyond the planning stages.

I would add a key additional factor needed to ensure the success of any educational change--faculty buy-in. It may be obvious to say that teachers must comprehend and commit to an educational change for that change to be successful. "Learning cannot change is teaching work doesn't change" (Ancess and Darling-Hammond 1994, p.29). However, that point is so often forgotten in "top-down" reform efforts. The affected faculty must be included in the process of the change--development, implementation and continuation. Compatibility among faculty members would be ideal, but a few key members should also possess skills in conflict resolution when this breaks down.

Future Directions

I envision eight critical issues that we should address as we prepare to implement this integrated curriculum in the fall of 1995. This is hardly an exhaustive list and other issues will likely surface as we progress.

1) *The evolving curriculum.* The curriculum should continue to evolve so that it becomes truly integrated. As we have presently configured the curriculum, we distinguished the biology from the chemistry topics. As we gain more experience in teaching this topic sequence, we will look for more links and less distinction between biology and chemistry topics. Collegial discussion of this issue can/will occur during our weekly meetings.

2) *Mentoring/support new faculty members.* Next year, the weekly meetings will provide support for the four founding teachers. For the long-term maintenance of this curriculum, however, we also need to plan to mentor and support new science faculty

members when a founding teacher leaves the school. Successful innovative curricula seldom last long once the teachers who developed these curricula depart (Charles Hardy, personal communication, 1995; Cuban 1992, p.240). A critical aid to new teachers will be the development of written curriculum materials (see issue #7). New teachers can also aid in the evolution of this curriculum, as they will bring new perspectives.

3) *Reduce fragmentation of students' learning experience.* Many factors contribute to the fragmentation of students' learning experience (see also issues #4, #5, and #6), but I will focus on the schedule. Although we have just completed changing the schedule at UHS, I would argue that further change is necessary. In *Horace's Compromise: The Dilemma of the American High School*, Ted Sizer (1984) presents a troubling picture of the typical high school, a place that forces teachers to compromise to meet the demands of the system. I found the most compelling of Sizer's criticisms to be the choppiness of the school day as exemplified by schedule of Mark, a typical but unremarkable student (p.71-76). In what might have been the most valuable activity that I have done as a Klingenstein fellow, I shadowed a student for a day at Horace Greeley High School in Chappequa, NY. I would suggest this activity to any teacher as a way to better understand their students. Horace Greeley is considered one of the best public schools in the country and my student, David, was one of its strongest students. Like Sizer's fictitious student Mark, David had a class in every one of eight periods. At the end of the day, I was exhausted. However, David still had play practice from 4:00-6:00 (he was the musical director for Pippin), music practice from 6:30-8:30 (he arranged songs for an *a cappella* singing group), and 1-2 hours of homework. How could he do this? Why was I

exhausted and he still able to go on? Beyond snide comments about my advancing age (which certainly may be part of the explanation), I would suggest that I attempted to connect and integrate all of the disparate experiences (classes) throughout the day and this effort was fatiguing. The irony here is that the schedule promotes disconnection, encourages the students to not integrate the material and skills that they learn. As Sizer suggests, "there is a frenetic quality to the school day, a sense of sustained restlessness" (p. 79) with "a high premium placed on punctuality... a low premium placed on reflection and repose" (p. 80). The best students (like David) learn to compartmentalize their learning, efficiently turning around information--they listen and take notes on the teachers' presentations and faithfully return that information to the teacher on tests and homework assignments. The rest of the students (like Mark) pass through the systematized, conveyer-belt of schooling the object of, but mostly unaffected by, the information being directed at them.

If I could make only one major change in secondary education, it would be to change the schedule under which most schools operate. I would like to see a schedule with fewer periods that meet for longer times. Some schools had successfully adopted a 10-day cycle--each day has four periods and each period meets for 90 minutes (Gerking 1995; Day 1995). A particular class meets every other day, five times within a 10-day cycle. The benefit to the student is fewer transitions within each day. Although the number of minutes that each class meets is equivalent to that of a class that meets every day for 45 minutes, there is a qualitative increase in the learning time because there are fewer stops and starts to disrupt learning and reflection. Opposition to this plan would likely come from many sectors (every sector?) of the school community. Math and foreign language teachers might be particularly opposed to this plan because they feel that students need regular (daily) exposure and repetition of material. However, this argument sounds suspiciously like the "mental discipline" argument of a century ago. Unfortunately, a change in the schedule can be the most divisive change a school can undertake. All teachers are affected as lesson plans need to be revamped, styles need to be varied (you cannot lecture for 90 minutes), and rhythms change.

The next three issues deal with students' past (#4), present (#5), and future (#6) educational experiences.

4) *Coordination with middle school science programs in the area.* I plan to have greater communication with science teachers at the middle schools from which we draw our students. I have been slow to initiate contact because of daunting numbers--we draw from other 30 middle schools. Skills and concepts that students have learned can be used as a foundation for their learning in high school.

5) *Coordination with other University High School courses.* Over the last nine years, UHS has had a freshman curriculum committee that provided teachers awareness of the skills, the topics, and the rhythm of other disciplines. As a result, I have used the same language in describing a conclusion to a lab report that the English teacher used to discuss paragraph construction. We will continue to seek links between the disciplines in the lower divisions--for example, discussion of ethical issues related to biotechnology--and better anticipate learning in

the upper division. We recently hired a physics teacher, Nasif Iskander, who had worked at the Exploratorium, the well-known, discovery science museum in San Francisco. He can help better coordinate the integrated biology and chemistry curriculum with the physics curriculum because he brings greater expertise in both the natural sciences and physics that we had possessed on the science faculty.

6) *Chart student outcomes.* As our students exit this integrated curriculum, I intend to chart their science achievement by traditional and alternative means. Naturally, I will examine their performance on the subject area SAT-II tests. In the past, our students have done very well by these measures. I am also interested in questions that may be more difficult to quantify or complicated by other variables. How do these students perform in Advanced Placement (AP) science courses and on the AP tests? How are enrollments affected? In the past, far fewer females than males took our AP chemistry and physics courses. Will more female take these courses in the future? How will our students perform in college science courses where most instruction occurs in the separate disciplines?

7) *Develop curriculum materials.* We plan to develop written curriculum materials, possibly a textbook. These materials will be necessary to support the integrated learning of our students--this fall, they must alternate between biology and chemistry textbooks. The students must rely on the teacher to bridge the isolated perspective of these texts. Written curriculum materials will also support new science faculty members and aid teachers at other schools to envision similar reform.

8) *Maintain contact with other innovative high school science programs.* Finally, I intend to maintain contact with other schools that have initiated innovative science curriculum to share experiences related to these issues of educational change. At the National Science Teachers Association meeting in March, several teachers gathered informally to discuss their experiences. At this gathering, Kelly Gatewood from Omaha (Nebraska) North High School christened the National Association of Integrated Science Teachers (NAIST). The NAIST already has twelve teacher members and we have been communicating by electronic mail.

Schools with Innovative Science Programs

Academy for the Advancement of Science & Technology, Hackensack, NJ. Integrated study of science and technology. I visited the school and talked to Don DeWitt, science teacher, on March 13, 1995.

Amador County Unified School District, CA. Integrated study of all science disciplines using projects and themes as a foundation. I attended a presentation by Gary Sokolis at the California Science Teachers Association meeting on October 16, 1993.

Central Park East Secondary School, New York, NY. Integrated study of science and math. I visited the school and attended classes on December 8, 1994.

Charlotte Latin School, Charlotte, NC. Integrated study of science and engineering for middle school students. I attended a presentation by Tom Dubick, science teacher, at the National Association of Independent Schools on March 3, 1995.

College Preparatory School, Oakland, CA. Coordinated study of biology and chemistry over two years for tenth and eleventh grade students. I attended a presentation by Julie Stokstad, science department chair, at the California Association of Independent Schools meeting in the spring of 1992.

Community High School, Ann Arbor, MI. Integrated study of earth science, biology, physics, and technology over three years for ninth through eleventh grade students. I attended a presentation by Madeline Drake, Elizabeth Stern, and Michael Mouradian, science teachers, at the National Science Teachers Association meeting on March 25, 1995.

Convent of the Sacred Heart School, New York, NY. Coordinated study of biology, chemistry, and physics over three years for ninth through eleventh grade students. I visited the school, attended classes, and talked to Keith Shepard, science department chair, in the fall of 1994.

Massachusetts College of Pharmacy and Allied Health Sciences, Boston, MA. Coordinated study of biology and chemistry over two years. I talked with Professors Fred Garafalo and Vin LoPresti in Boston on March 2, 1995.

Omaha North High School, Omaha, NE. Integrated theme-based, study of biology and chemistry over two years for ninth and tenth grade students. I talked with Kelly Gatewood and Susan Koba, science teachers, at the National Science Teachers Association meeting on March 25, 1995.

Punahou School, Honolulu, HI. Integrated study of biology, geology, chemistry, math, and physics over two years for ninth and tenth grade students using the theme of time. I talked by phone with Jerry Devlin, science teacher, in September, 1994.

Stuyvesant High School, New York, NY. Integrated study of chemistry and physics over one year (double periods) for tenth or eleventh grade students. I visited the school and attended the classes of Miriam Lazar, science teacher, on February 8, 1995.

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Appendix

Biology and Chemistry - Two-Year Integrated Program

University High School
San Francisco, CA

Application for Curriculum Approval
University of California
July 25, 1994

Textbooks Heath *Biology*, McLaren et al., D.C. Heath and Company, 1991.
Heath *Chemistry*, Herron et al., D.C. Heath and Company, 1987.

i. Overall Organization of Coursework

Integrated Biology and Chemistry I - Ninth Grade

FALL

A. Scientific Method/Characteristics of Life
B. Introduce Human Biology/Respiratory System
C. Gases - volume/composition/properties - combustion products
D. Diffusion/Osmosis
E. Circulatory System
F. Combustion/Qualitative Energetics
G. Descriptive Kinetics

SPRING

H. Digestive System/Excretory System
I. Reproductive System
J. Diversity of Life (Five Kingdoms)
K. Chemical Separations
L. Ecology

Integrated Biology and Chemistry II - Tenth grade

FALL

M. Atomic-molecular theory
N. Electronic structure of atoms
O. Molecular structure
P. Physical properties
Q. Chemistry of organic functional groups
R. Molecules - Carbohydrates, lipids, nucleic acids, proteins
S. Stoichiometry
T. Energetics - quantitative
U. Aqueous solutions

SPRING

V. Kinetics - quantitative
W. Cells/organelles
X. Acid/base
Y. Equilibrium - quantitative
Z. Reduction/oxidation reactions
A'. Tools of Biotechnology
B'. Genetics
C'. Evolution/History of Life

Narrative Overview of Overall Organization of Coursework

We have developed a two-year curriculum that integrates Biology and Chemistry for the ninth and tenth grades. Traditional high school science education divides study into the separate disciplines. However, many state and national organizations recommend integrated science curricula including the California State Board of Education, the National Science Teachers Association, and the National Academy of Sciences. These organizations support our argument that students would be better served by an integrated study of biology and chemistry for two fundamental reasons. First, an integrated approach is a better way to learn science given the intellectual co-dependence of biology and chemistry. The living state ultimately results from interactions between molecules and atoms, commonly thought to be the realm of chemistry. The study of any topic in biology would be enriched by an understanding of the supporting chemical principles. Second, a host of public policy decisions and ethical dilemmas surrounds recent advances in biotechnology and genetics. If our students are to be prepared participants in these decisions, they must possess an integrated understanding of biology and chemistry as well as recognition that scientific discoveries often have social consequences.

Our proposed curriculum matches the cognitive development of ninth and tenth grade students. Topics progress from the concrete to the abstract, i.e., we begin with the study of organisms and later consider the underlying cell and molecular phenomena. In fact, the first semester is framed by study of the organism most meaningful to students - humans.

During the first year, we will focus on the study of biology and develop the need to delve deeper to learn chemistry. Topics normally taught during Chemistry courses will be presented in an introductory or qualitative fashion at relevant junctures in our study of organismal biology. These topics will be examined quantitatively or in greater depth in the second year. For example, a descriptive introduction to rates of reactions (kinetics) and the effect of catalysts will precede the study of the digestive system. Organic molecules will be loosely defined as large molecules broken down to building blocks during the digestive process. (Most students have, at the least, heard the terms carbohydrates, lipids, and proteins.) Rigorous definitions of these organic molecules are left to the second year, after study of atomic and molecular structure. Further examination of kinetics will include quantitative terms. By the end of the two-year sequence, we feel that each discipline, biology and chemistry, will be equally well served.

Units on biotechnology, genetics, and evolution provide a pedagogically appropriate closure to an integrated biology and chemistry curriculum. Students would apply their understanding of both subjects to explore the related ethical, legal, and societal issues of contemporary scientific problems. The fruits of biotechnological advances have already reached our supermarket shelves (literally), our pharmacies, and affected our judicial system. Unreasonable fears abound. "Environmentally-conscious" chefs in the Bay Area have decided not to serve the genetically altered tomato, though nearly all of our food crops have been altered genetically through selective breeding over the last two thousand years. Reasonable concerns have also been raised. If a genetic disease can be detected but not corrected, will affected individuals be discriminated against? Will they be able to find health insurance? As employers increasingly insure their employees, will affected individuals be able to find employment? Our students can be and should be familiar with the rudimentary techniques of biotechnology to assess such issues. As the English, History, and Arts teachers at our school are considering an integrated Humanities curriculum for the 9th and 10th grades, we have the unique opportunity to develop units that could at the least underscore thematic connections across the entire lower division curriculum.

ii. Essential Concepts to be Explored - Essential Concepts (in **bold type**) from "Statement on Preparation in Natural Science Expected of Entering Freshmen" published by the University of California in July 1986. The numbers indicate the essential concept from the biology (Bio) section or the chemistry (Chem) of that document. The letters correspond to the topic sequence of our integrated biology and chemistry curriculum (see page 83).

A. Scientific Method/Characteristics of Life

1. (Bio) **The Cell - Building Block of All Life Forms** ***(briefly, later more detail)***
    - **introductory section presenting an overview of course**
    - **cell structure**
    - **biological organization**
    - **utilization of energy by living systems**
    - **growth**
    - **response to stimuli**
    - **cellular and organismic adaptation**
    - **cells, tissues, organs in humans beings**
    - **introduction to principles of evolution**

1. (Chem) **Introductory Concepts - Definitions and Examples** ***(briefly, later more detail)***
    - **states of matter**

B. Introduce Human Biology/Respiratory System

12. (Bio) **Human Biology**
    - **overview of anatomical structure and function**
    - **system analyses**
    - **cell biology and metabolism** ***(briefly, later more detail)***
    - **organ physiology**

C. Gases - volume/composition/properties - combustion products

8. (Chem) **Gases**
    - **the kinetic molecular theory of gases (qualitative)**
    - **pressure and its measurement - units of pressure**
    - **temperature and temperature scales - Kelvin scale**
    - **Boyle's law**
    - **Charles' law**

D. Diffusion/Osmosis

3. (Bio) **The Structural Basis of Life**

movement of materials across cell membranes

E. Circulatory System

F. Combustion/Qualitative Energetics

14. (Chem) **Energetics and Dynamics**

energy changes during physical changes & chemical reactions

G. Descriptive Kinetics

effect of changes in temperature
effect of catalysts
potential energy diagrams

H. Digestive System/Excretory System

2. (Bio) **The Chemical Basis and Requirements of Life** ***(briefly, later more detail)***

molecules essential to the functioning of living systems

their molecular structure and biological role -
proteins, lipids, and polysaccharides

energetics of chemical reactions - including the role of enzymes and other catalysts

I. Reproductive System

12. (Bio) **Human Biology**

human reproduction and sexuality
human embryology and development

J. Diversity of Life (Five Kingdoms)

8. (Bio) **Taxonomy**

classification (reasons for and concepts of)
contributions of Linnaeus
modern taxonomic systems
scientific nomenclature
present-day classification systems
phenetic and phylogenetic trees

9. (Bio) **Animal Phyla, Physiology and Behavior**

major classes of animal organisms
  invertebrates
  vertebrates
their structural and functional similarities and differences
their evolutionary relationships
major systems of vertebrates
  system-by-system analysis
  application of basic principles to humans
energy systems in animals
neurobiology systems
behavioral patterns

10. (Bio) **Plants and Protists**

major classes of plant organisms
botanical principles
plant structures
protists in the web of life
structure, evolutionary relationships, functional differences, economic significance, organizational complexity of the following groups of organisms:
  viruses and bacteria, protozoa, fungi, algae
  mosses, liverworts, and ferns
  gymnosperms, angiosperms
role of plants and protists in nutrition and medicine
applications in modern agriculture and technology ***(briefly, later in more detail)***

K. Chemical Separations

1. (Chem) **Introductory Concepts - Definitions and Examples**

states of matter
chemical and physical properties
pure substances and mixtures
heterogeneous and homogeneous substances
physical change
chemical change

L. Ecology

4. (Bio) **Energetics of Life**

overview of energy processes within organisms

(later include cell structures and organelles)

cellular respiration *(briefly, later in more detail)*

photosynthesis *(briefly, later in more detail)*

uses and conversions of chemical energy

the balance of autotrophs and heterotrophs

predator-prey relationships

the balance of chemical and energy cycles

energy flow within a community

impact of human society on the natural environment

11. (Bio) **Ecology**

structure and function of ecosystems; population biology, community structure

demographics and the environment

wise use renewable and non-renewable resources

the "agricultural revolution" -- its consequences for population growth etc.

control of pollution and toxic waste

conservation of natural resources

16. (Bio) **Biology and Human Affairs**

public participation in scientific undertaking

using knowledge to reach informed decisions

careers and avocations in biology

ethical and moral considerations in biology

M. Atomic-molecular theory

1. (Chem) **Introductory Concepts - Definitions and Examples**
   states of matter
   chemical and physical properties
   pure substances and mixtures
   heterogeneous and homogeneous substances
   physical change
   chemical change

3. (Chem) **The Atomic Nature of Matter - Atoms and elements**
   the atomic theory
   the nuclear atom
   subatomic particles - protons, electrons, neutrons
   qualitative introduction to atomic structure
   elements - atomic number
   chemical symbols and names of the elements
   isotopes - mass number
   atomic mass unit - relative weights of atoms
   ion formation through electron gain or loss
   the charges and nomenclature of common monatomic cations and anions

4. (Chem) **Introduction to the Periodic Table**
   atomic number and the periodic table
   classification of elements according to the periodic table -
   main group elements, transition elements
   physical properties of the common elements - common physical states, densities
   chemical formulas of the elements - allotropes
   chemical families - names of the families and some simple illustrations of the chemical and physical properties of families

2. (Bio) **The Chemical Basis and Requirements of Life**
   atoms, molecules, chemical bonds and reactions

N. Electronic structure of atoms

5. (Chem) **Compounds and Chemical Formulas**

elements and compounds
binary compounds: molecular and ionic
nomenclature of binary compounds
molecules and ions containing three or more elements
formulas and names of common polyatomic ions
nomenclature of salts

11. (Chem) **Chemical Bonding**

the concept of valence electrons in atoms
Lewis dot representation of atoms
Lewis dot representation of monatomic (sic) ions
relative sizes of monatomic cations and anions compared to atoms
the Lewis concept of covalent and ionic bonds
the concept of electronegativity - polarity of bonds in diatomic molecules
Lewis structures in simple molecules - the use of the octet rule

O. Molecular structure

10. (Chem) **Geometry of Simple Molecules and Polyatomic Ions**

classification of common molecules and ions based on a central atom and pendant (ligand) atom
geometric structure of simple molecules and ions
linear and bent triatomic molecules (2 ligands)
pyramidal and trigonal planar geometries (3 ligands)
tetrahedral and square planar geometries (4 ligands)

P. Physical properties

9. (Chem) **Solids and Liquids**

comparison of the properties and characteristics of gases, liquids, and solids
phase changes: evaporation and condensation; melting and solidification; sublimation
heat changes accompanying phase changes
qualitative introduction to the concept of dynamic equilibrium
vapor pressure - boiling point
qualitative structural picture of the nature of crystalline solids and of liquids

Q. Chemistry of organic functional groups

R. Molecules - Carbohydrates, lipids, DNA/RNA/proteins

2. (Bio) **The Chemical Basis and Requirements of Life**
    atoms, molecules, chemical bonds and reactions
    molecules essential to the functioning of living systems
        their molecular structure and biological role -
        proteins, nucleic acids, lipids, and polysaccharides
    energetics of chemical reactions - including the role
        of enzymes and other catalysts ***(more detail)***

S. Stoichiometry

2. (Chem) **Measurement - Definitions and quantitative application**
    measurement systems - the metric system and SI units
    scientific notation - it relationship to metric prefixes
    the qualitative concept of precision and error
    dimensional analysis and unit conversion - emphasis on mass, volume, density

6. (Chem) **Calculations and Chemical Formulas**
    the mole
    molecular weight (formula weight)
    Avogadro's number
    mass-to-mole and mole-to-number interconversions
    elemental composition (percent composition)
    empirical formula determination

7. (Chem) **Chemical Equations and Calculations**
    writing and balancing equations
    conservation of atoms and charge, and the meaning of a balanced equation
    conservation of mass and reaction stoichiometry - including mole-to-mole,
        mole-to-mass, and mass-to-mass calculations
    the yield of a reaction and percent yield
    limiting reagent calculations

8. (Chem) **Gases** ***(more detail)***
    Boyle's law
    Charles' law
    Avogadro's law - law of combining volumes
    the ideal gas law
    standard temperature and molar volume
    stoichiometry problems involving gases

T. Energetics - quantitative

14. (Chem) **Energetics and Dynamics**

energy changes during chemical reactions

U. Aqueous solutions

12. (Chem) **Solutions**

water and its properties
solutes and solvents
electrolytes and nonelectrolytes in aqueous solution concentration
concentration units - percent by weight, molarity
calculations involving interconversions among moles, mass, volume, and molarity, including dilution

13. (Chem) **Chemical Reactivity**

a. Precipitation Reactions in Aqueous Solutions

qualitative aqueous solubility of common salts
strong electrolyte character of most common soluble salts
deduction of a chemical equation for a precipitation reaction using the solubility data for common salts

V. Kinetics - quantitative

first order rate law
effect of changes in temperature
effect of catalysts
potential energy diagrams

W. Cells/organelles

3. (Bio) **The Structural Basis of Life**

structure of plant and animal cells
the cellular environment
movement of materials across cell membranes (revisited)
movement within the cell
levels of organization in multicellular organisms
nature and role of anaerobiosis and fermentation - applications to humans and medicine

4. (Bio) **Energetics of Life *(more detail)***

overview of energy processes within organisms
cellular respiration
photosynthesis
uses and conversions of chemical energy

5. (Bio) **Growth and Reproduction**

comparison of roles of meiosis and mitosis in cellular and organismic reproduction
sexual and asexual reproduction - alternative means of species perpetuation

X. Acid/base

13. (Chem) **Chemical Reactivity**

b. Acid-Base Reactions in Aqueous Solution

Arrhenius and Bronsted-Lowry definitions of acids and bases
nomenclature of common inorganic acids and bases
strong electrolyte character of many common acids and bases
the neutralization reaction
deduction of a chemical equation for an acid-base reaction using the neutralization reaction - emphasis on common strong acids and bases
definition of pH - qualitative applications
acid and base precursors - oxides of nonmetals and oxides of metals

Y. Equilibrium - quantitative

14. (Chem) **Energetics and Dynamics**

dynamic equilibria in chemical systems
Le Chatelier's principle

Z. Reduction/oxidation reactions

13. (Chem) **Chemical Reactivity**

c. Oxidation and Reduction Reactions

descriptive chemistry of oxygen and the halides, including the preparation of simple oxides and halides of main

group elements as examples of oxidation and reduction

descriptive chemistry of Group I and II representative metals, including the action of other active metals on aqueous solutions - generation of hydrogen gas

combustion of simple hydrocarbons

definition of oxidation and reduction

concept of oxidation numbers

balancing simple equations by half-equation method

practical applications - combustion and batteries

A'. Tools of Biotechnology

13. (Bio) **Health and Major Diseases**

public health and modern medicine

principles of genetic counseling

potentials of bioengineering

concepts and controversies in human health and fitness

5. (Bio) **Growth and Reproduction**

potentials of bioengineering

reproductive technology in agriculture and medicine

10. (Bio) **Plants and Protists**

applications in modern agriculture ***(more detail)***

B'. Genetics

7. (Bio) **Principles of Heredity**

chromosomal theory of heredity

Mendelian genetics and improvement of crops

gene-enzyme relationships - their application to human inheritance

C'. Evolution/History of Life

6. (Bio) **Evolution**

history of life and organic diversity

survey of organic evolution and speciation

synthesis of genetic variation and natural selection in effecting morphological, physiological, and behavioral changes in populations over time

evidence and logic in defining the evolutionary process

evidence from fossils

interpretations of human evolution

iii. General Demands Made Upon the Students

Written/Oral Expression

Lab Reports - 1-2 pages, assigned 2-4/month

Presentations - oral and written

ex. report on an element, an organelle, etc.

Tests - subjective/objective sections include essay

Laboratory exercises/activities - see next section.

Each course meets 205 minutes per week - three 45 minute periods and one 70 minute block.

Laboratory exercises occur once per week during the 70 minute block.

Additional hands-on activities and demonstrations can occur more than once per week during the 45 minute periods.

iv. Prerequisites and Corequisites

no prerequisite to Biology and Chemistry A

level of math sophistication - students must be in (or above) Algebra I

v. Methods of Assessment

tests	60% - 70%
lab reports	20% - 30%
additional written work short written assignments oral and written presentations	10%

daily preparation - ungraded, but a contributing factor

reading

participation in class discussions

vi. Laboratory Exercises/Activities (in **bold type**). The letters correspond to the topic sequence of our integrated biology and chemistry curriculum (see page 83).

A. Scientific Method/Characteristics of Life

importance of being a good observer, accurate recording

-Observational activity - partner, pillbug

write down all observations

reconstruct organism on butcher paper from descriptions

scientific communication

reproducibility/consensus - same pillbug, different observations

observation vs. inference, bias

students better at distinguishing/describing partner than pillbug

What characteristics do your partner and a pillbug share?

leads into Characteristics of Life (Unity)

what do living things need?

processes, structures

How can you distinguish something that is dead from something that was never alive? (Sophisticated question - pose now, answer later)

-Observational activity - Microscope Work

extend observations with technology

cheek cells, aquatic plant (Elodea), onion membrane

cell theory (pick up cells again with circulation)

B. Introduce Human Biology/Respiratory System

-Observational activity - partner at rest, active

heart rate, resp rate, flushed, sweat

extend observations with technology - stethoscope

later blood pressure cuff, respirometer, EKG

-Effect of temp on Goldfish resp rates - Student design

C. Gases - volume/composition/properties - combustion products

- **-volume of inhaled/exhaled air**
  - **low tech - exhale into bag, displace H_2O**
  - **high tech - respirometer**
- **-distinguish inhaled/exhaled air**
  - **CO_2 content via acid-base indicator**
  - **H_2O content (condensation, cobalt chloride paper)**
    - (same products as combustion)
  - **combustion consumes O_2, N_2 remains**

combustion products - nature of flames (preview energetics)

- **-candle, wax alone - tests for CO_2 and H_2O**
- **-methane (Bent's flame demonstration)**
- **-complete, incomplete combustion**
- **-diffusion (normal candle) and premixed (blue) flame(s)**
- **-students light and adjust burners**

D. Diffusion/Osmosis

- **-demonstrate - methane, ammonia into room air, sealed tubes of I_2, Br_2**
- **-NH_3 + HCl (open bottles) - quantitative(?) extension - molecular speeds**
- **-I_2 or $KMnO_4$ crystal in solvent, cold vs. hot (molecular model)**
- **-osmosis labs - potato pieces, blood cells, Elodea cells**
  - **in different concentrations of sugar water**
- **-bell jar - beaker of H_2O, beaker of H_2SO_4**
  - **measure mass of each over time -> graphing**
  - **molecular activity, water vapor in the air ("osmosis")**
- **-Kinetic molecular model demonstrator**
- **-PV measurements - graphing, pressure units, scuba diving**
- **-VT measurements - graphing, absolute temperature, metric units, prefixes**
- **-I_2 diffuse into bag of starch**

E. Circulatory System

- **-stethoscope/blood pressure/EKG**
- **-Beef Heart dissection**
- **-Daphnia heartrate at different temp**
- **-microscope -> capillaries in Goldfish tail**
- **-Fetal Pig Dissection - start with thoracic cavity**
  - **reinforce respiratory, later used with digestive/reproductive**

F. Combustion/Qualitative Energetics

qualitative enthalpy diagram

matter - source of C in CO_2, source of H in H_2O

reactants vs. products (word equations)

-candle wax or oil lamp ("lipid")

-calorimeter - measure mass and temperature changes

-enthalpy diagram, energy barrier

-glucose (recall H_2SO_4 "dehydration")

-flour explosion (demonstration)

-Mg burned in air (measure masses), O_2, CO_2

(sources of oxygen?)

-$KMnO_4$ + glycerol flame

Other exo-, endothermic reactions

-solution/crystallization - anhydrous $CaCl_2$, NH_4NO_3, supersaturated sodium acetate

-phase changes - cooling curve (note T of water bath during phase change

- energy involved in changing T or phase) - note reversibility

(Equilibrium introduction)

G. Descriptive Kinetics

surmounting the energy barrier

kinetic molecular model, continued

-effect on reaction rate of

changes in temperature

catalyst (inorganic/organic: MnO_2, liver + H_2O_2 demo)

pH and/or other concentration

-effect of temperature on catalyst (inorganic/organic)

(recall effect of temp on respiratory rate of goldfish)

-effect of acid/base/salt on catalyst (inorganic/organic)

H. Digestive System/Excretory System

-food (types of organic molecules) tests

-semipermeable membrane revisited

leads to chemical separation

I. Reproductive System

-chick, sea urchin development

-sheep testes dissection

-microscope work - slides of sperm/eggs

-demonstration - HCG + pregnancy tests

J. Diversity of Life (5 Kingdoms)

Plants

1. Reproduction/growth/development
   -sexual (plant seeds)/asexual (cuttings)
   -flower dissection
2. Respiration
   -Elodea/Daphnia in tubes of dilute acid-base indicator
3. Nutrition
   -leaf design - structure/function
   anticipate biomes (Oleander stomates lined by hairs)
4. Support
   -roots/shoots (prepared slides)
   -tropisms

Animals

-research Project
(each student becomes an expert on a specific animal phylum)

-observational Activity

vertebrates (human, frog, fish)
arthropods (aquatic, terrestrial)
mollusks (aquatic, terrestrial)
echinoderm
sea anenome
earthworm

for each organism, consider

1. Support
2. Nutrition
3. Respiration
4. Reproduction

Plant/Animal Taxonomy (follow water->land theme for plants/vertebrates)
-observational activity for plants

Other Kingdoms - Fungi/Protista/Monera
-microscopic observational activity
use protists to discuss uncertainty of classification

-student-designed dichotomous key for all kingdoms
(Summary activity)

K. Chemical Separations

-demonstrate separation techniques - filtration, dissolving, distillation, sublimation, paper chromatography (black ink, chlorophyll, food colors), centrifuge (ultra-)

-separation lab applying one of the above techniques

-demonstrate - electrolysis of H_2O (note volume ratio)

another kind of "separation" (introduce electrophoresis)

sources and fates of substances - chemical cycles

chapter on carbon cycle in Primo Levi, **Periodic Table**

minerals/stellar synthesis/metallurgy

distinguish substances, compounds vs. elements

-synthesis and analysis - MgO preparation (combining masses)

(via method of continuous variations?)

-demonstration - CuO reduction

L. Ecology

a. Biomes - How would you build animal/plant to live here?

-leaf observational activity

-soil comparison

b. Ecosystems

food chains - energy flow/chemical cycles

-*Predator* card game

c. Human Impact

-student research/presentation on a topic

examples - Biological Magnification, acid rain, ozone depletion, greenhouse effect, habitat destruction (forests, wetlands) and loss of biodiversity

M. Atomic-molecular theory

explaining combining masses in compounds (MgO lab, CuO demonstration)

explaining combining volumes (electrolysis demonstration)

distinguishing substances in terms of atomic composition

Periodic Table

-Element report assigned

representative elements - emphasis on C, N, O

metals/nonmetals, states, trends

N. Electronic structure of atoms

charge density

-hydrogen atom target

s, p orbitals (OP transparencies)

electron configurations (through atomic number 20, main group elements by analogy to representative elements)

octet rule as guide to monatomic ion structures

O. Molecular structure

the chemical bond - charge density model again (more OP transparencies)

octet rule as guide to formulas involving electron sharing

molecular geometry - VSEPR model

-molecular models

bond properties - length, strength, polarity

-Element report due

P. Physical properties

-relative melting point, solubility in polar/nonpolar solvents, conductivity

-include organic functional groups (pool student data)

forces within/between units of structure

covalent (also ionic, metallic) bonds

dispersion and dipole forces, hydrogen bond

-solubility curve (more on equilibrium; compare unsaturated, super-)

-vapor pressure of butane (demonstration)

Q. Chemistry of organic functional groups

hydrocarbons

alcohol, acid, amine (aldehyde, ether) -> ester, amide

-esterification - small-scale labs

-soap - demonstration

-polymers (nylon) - demonstration or small-scale lab

R. Molecules - Carbohydrates, lipids, DNA/RNA/proteins

carbohydrates/lipids

enzymes mechanisms, metabolism

DNA/RNA/proteins

-models, videos of replication, protein synthesis

S. Stoichiometry

mass and volume ratios -> atom and molecule ratios

relative and absolute masses -> atomic, molecular, and formula masses

-**Mg + HCl stoichiometry** (continuous variations?)

-Avogadro's number by monomolecular film

-MgO, CuO revisited

formulas - simplest and molecular

equations

ideal gas law

T. Energetics - quantitative

quantitative, written into balanced equations

enthalpy diagrams for reactions

relative strengths of bonds (energy stored and released)

U. Aqueous solutions

concentration - molarity, molality(?)

-molecular mass determined from freezing point depression data

-technology - molarity via spectrophotometry

V. Kinetics - quantitative

-rate law - dependence of rate on concentration

(S or I clock)

W. Cells/organelles

membrane structure/active transport

compartmentalization

X. Acid/base

proton transfer definition (Bronsted-Lowry)

strength - equilibrium, K_w, K_a and % ionization, conductivity, pH

acid-base reactions, neutralization

indicators - demo red cabbage

-technology - pH meter

-titration of a household product (Tums, vinegar)

inorganic acids/bases and anhydrides -> acid rain, shuttle launch

carboxylic acids

buffers - later refer to electrophoresis

human pH "balance" - refer back to respiration/excretion

-$CaCO_3$ + acetic acid, with/without acetate - demonstration

equilibrium "shift"

Y. Equilibrium - quantitative

Z. Reduction/oxidation reactions

electron transfer (partial/complete)
oxidation number/state
electronegativity
Periodic Table trends, group behavior
balancing redox equations

-voltaic pile, dry cell - demonstration
-cell voltages - small-scale lab
-concentration cell - demonstration (refer to nerve impulse)

A'. Tools of Biotechnology

-restriction digestion analysis of DNA
DNA fingerprinting

B'. Genetics

-bacterial transformation (follow-up on biotech labs)
-plant crosses - Wisconsin fast plants
-fruit flies crosses

C'. Evolution/History of Life

chemical basis of evolution
-organic chemical evolution (Miller-Urey experiment)
-field trip to Academy of Sciences - Live Through Time exhibit

last 3 sections are good summary units
biology content, but requires heavy-duty chemistry