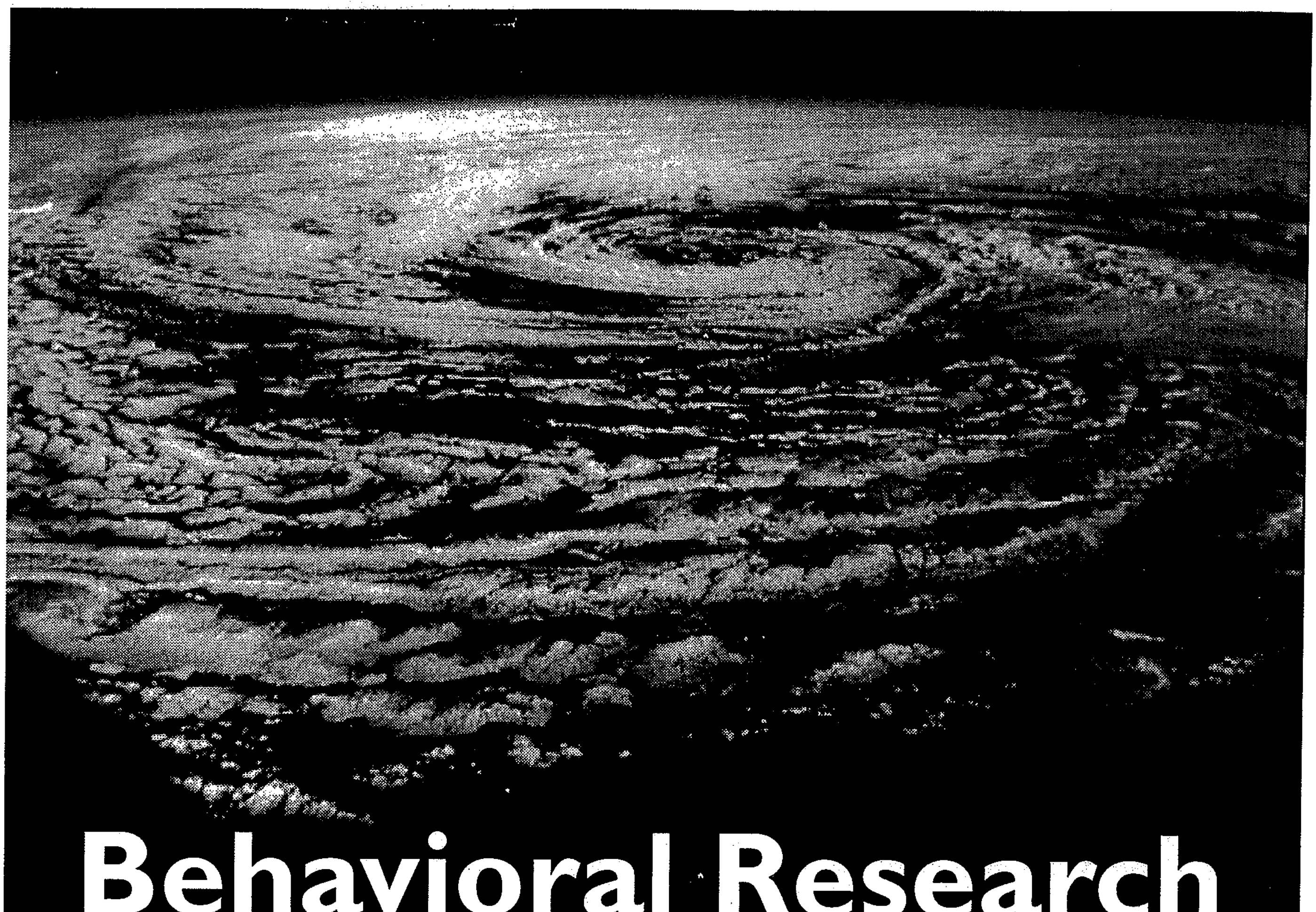

Behavioral Research and Teaching

Understanding Science Benchmarks by Anchoring Student (Mis)understanding

Gerald Tindal, Ph.D.
Jennifer McCleery

Research, Consultation, and Teaching Program
University of Oregon
Eugene, Oregon

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Abstract

Current efforts in science instruction emphasize the need for higher standards and outcomes as well as performance assessments using problem-solving to document these outcomes. Much of the literature on performance assessments, however, is written as if validity issues have been resolved and that the connection between assessment and instruction is strong. Yet, further performance assessment research is needed to determine whether problem-solving tasks tap different types of knowledge and whether solutions to problems are influenced by student misconceptions. In this study, a science unit on matter was taught to four classes of sixth-grade students and an outcome measure was administered that included both fact label matching and problem-solving essay tasks. The results indicate that knowing facts was somewhat related to solving problems. Nevertheless, some consistent misconceptions also were present. Yet, these misconceptions appeared to tap a different function: They were not highly predictive of problem-solving performance. Finally, student self-evaluations were inaccurate for both types of factual and problem-solving performance. The most obvious implications involve the manner in which educators use student (mis)understanding to influence teaching and learning.

Understanding Science Benchmarks by Anchoring Student (Mis)understanding

Schools are currently portrayed in the popular press as being muddled in mediocrity, with the science performance of students in the United States woefully lagging behind students in most other industrialized countries. For example, among 13 and 14 year olds, the United States ranked 7th of 14 countries in the first international science study (1966-1973), 14th (of 17 countries) in the second international science study (1983-1986), and 9th of 12 countries in the first international assessment of educational progress (1988). "The evidence suggests, in general, that students from the United States have fared quite poorly on these assessments, with their scores lagging behind those of students from other developed countries" (United States Department of Education, 1992, p. viii). More specifically, on the National Assessment of Educational Progress, 13 year olds exhibited the following proficiency levels in the various areas of science achievement on the 1989-1990 measures: 92% understood simple scientific principles, 57% applied basic scientific information, 11% analyzed scientific procedures and data, and .5% integrated specialized scientific principles (United States Department of Education, 1993).

One response made by the science educational community has been to establish standards, which move beyond simple multiple-choice tests of declarative knowledge and toward performances of both an attitude and an approach to problem-solving. For example, the science benchmarks for the structure of *matter* noted by Project 2061 (American Association for the Advancement of Science, 1993) include the following for each of several grade levels:

1. Kindergarten through Grade 2: "Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them" (p. 76).

2. Grades 3 through 5: "Materials may be composed of parts that are too small to be seen without magnification...When a new material is made by combining two or more materials, it has properties that are different from the original materials. For that reason, a

lot of different materials can be made from a small number of basic kinds of materials" (p. 77).

3. Grades 6 through 8: "All matter is made of atoms, which are far too small to see directly through a microscope. The atoms of an element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances" (p. 78).

While these standards appear to reflect a broadly endorsed direction by the science community and are being promulgated in the many (sub)disciplines in the physical, biological, and chemical areas, they also reflect great latitude in formulating appropriate tasks and generating reliable and valid scoring and decision-making systems. As noted in the benchmarks for *matter*, students must understand atoms as the building blocks of matter to understand elements, mixtures, and compounds, or to distinguish between physical and chemical changes. And, a very wide range of tasks can be devised to determine whether students understand the intricacies of atoms (e.g., their similarities, arrangements, and compositions into solutions and mixtures). Finally, understanding is likely to be more complex than "all-or-nothing" in its final state; rather, it is likely to vary, with conceptions and misconceptions not clearly separate.

The question, then, is the degree to which such standards can be met and also accommodate the reality of measuring student understanding. In this paper, we investigate two components of achievement in science, using a unit on *matter* for sixth grade students to explicate the distinction between declarative knowledge and procedural-conditional knowledge (Alexander, Shallert, & Hare, 1991) and to describe student understanding of concepts of *matter* in several ways. To accomplish this objective, we considered two tacts for this study. First, we hoped to develop an assessment system that reflected the American Association for the Advancement of Science (AAAS) standards; second, we anchored "understanding" by documenting performance across different dimensions: (a) format of measurement (allowing us to consider labels for factual knowledge versus problem-solving essay performance), (b) relationships of performance across different concepts, and (c) misconceptions of performance (both objectively measured and as part of student self-evaluations).

Types of Knowledge

In the classrooms for this study, the teachers' purpose for testing was to summatively evaluate student end-of-unit performance to assign grades. We, however, were more interested in looking at classroom learning of concepts, both the factual and procedural-conditional knowledge. In essence, we analyzed item consistency and difficulty on a test that included both label-matching items on concept definitions and extended essay responses to problem-solving prompts. Our focus was on the relationship between these two formats for demonstrating knowledge. For example, when looking at student learning of organic compounds, an important concept in a unit on matter, how many students correctly answer definitional (factual) questions and how many answer problem-solving short-answer questions requiring them to illustrate or evaluate a scientific principle about organic compounds? And are these the same students?

"When we know something, (be it content, linguistic, or otherwise), we can know not only factual information about it (declarative knowledge), but also how to use such knowledge in certain processes or routines (procedural knowledge). We can also understand when and where this knowledge would be applicable (conditional knowledge)" (Alexander, Schallert, & Hare, 1991; p. 323). These three types of knowledge are generally viewed as being distinct: Acquisition in one form does not automatically translate or transfer into acquisition in the other forms. "Thus it is certainly possible to know the what of a thing without knowing the how or when of it" (p. 323).

By organizing the unit of analysis around the concept, the focus of analysis was not on how well a student performed, but on how well a concept was learned and how the learning of one concept related to the learning of other concepts. This analysis, in turn led us to another way of looking at learning: through the student's perception of understanding.

Documenting Student Understanding

Another way to think about operationalizing understanding is through misconceptions. Not only should we be well-versed in knowing what students know, but also in what they think they know. The second purpose of this study, therefore, was to identify student misconceptions.

One important use of student performance assessments should be to identify student misconceptions, hopefully before it is too late and ideally to structure enough remediation to correct them. Nickerson (1985) summarizes a number of studies in math and science in which fundamental student misconceptions had been identified, many of which were nearly impervious to correction (i.e., occurred with college students having had many educational classes in a specific content area). In the end, he raises several issues about what it means to "understand," two of which we address in this study: (a) understanding is not a binary event, "an all-or-nothing affair" (p.226), and (b) "the more knowledge one has that is related to a concept (mechanism, process, principle, relationship or whatever), the greater one's understanding is likely to be" (p. 234).

Misconceptions can be studied by noting the discrepancy between what students think they know and what actually is (Guzzetti, Snyder, Glass, and Gamas, 1993). In general, it appears that instructional strategies that build from "cognitive conflict" are more effective in increasing student performance. "Text can be used effectively to eradicate misconceptions either when text use is refutational or when text is used in combination with other strategies that cause cognitive conflict. Results show no efficacy, however, in using nonrefutational expository text (the type of text most commonly found in textbooks) as a single intervention" (p. 130). The problem for teachers is in seeing the misconceptions and framing them into a pattern.

Summary of Study Focus

In this study, we used a two-part outcome measure to investigate student understanding of *matter*. In the first part, a traditional fact (label) test included matching and labeling parts of the atom. In the second part, students had to apply their knowledge in understanding compounds, inorganic compounds, and distinguishing *physical* from *chemical* change and as well as explain *solutions* and *mixtures*. The most important question addressed the relationship between these two elements of learning: the relationship between knowing factual labels and performing on problem-solving tasks and subsequently, the impact of misconceptions on this performance.

Method

This study was conducted in four sixth grade science classrooms in a district of almost 4,200 students; the middle school had just over 450 students in attendance. It was done during a two-week unit on matter in the fall of the school year. The school had been ranked 75th in socio-economic status using a state formula (weighting parent education, number of students receiving free or reduced lunch, and family income).

Subjects

Three teachers taught a total of 91 students in this study. They all were certified to teach in elementary schools, had 1, 13, and 15 years of teaching experience, most of this with the current district, in middle schools, and in science. Two teachers had a Master's degree and some additional professional development credits (9-45), the other teacher had a Bachelor's degree with 109 additional credits.

The student population included 30 students who were receiving supplemental support services from Title 1 (n = 10), special education (n = 11), or talented and gifted programs (n = 9). Ninety percent of the students were Caucasian, with 5% African American, about 4% Asian-Pacific, and just 1% Hispanic (no data were available on 12 students). The number of boys (n = 42) and girls (n = 49) was nearly equal and equally distributed in general and special education. The students were taught by three teachers and were in either a morning or afternoon class. One teacher taught two sections. In the end, this group of students had missed about 3 days during the trimester (27 days overall) and had an average grade distribution (the mode receiving grades of C and the grade point average being just below 3.0 on a 4-point scale for both the trimester and the year). On statewide tests in math and reading, the group performed at about the 59th percentile rank in math and 46th percentile rank in reading (total test performance was 55th percentile rank). See Table 1.

Procedures

We began the study by asking teachers to identify up to 12 key concepts, from the curriculum and their own experience in teaching the unit previously, that they valued and believed necessary for student learning for a unit on *matter*. The role of each concept was to act as an umbrella for the unit of study to be presented by defining, organizing and linking knowledge of the present curriculum to student schemata and to provide transferability. For each concept, the teachers clearly identified its attributes and some examples and non-examples. Teachers also identified up to three principles (or rule relationships) which they wanted students to know and use by the end of the unit. These principles helped organize and link the key concepts together. This identification process was done prior to the beginning of the unit; the words they targeted were then used in the other analyses.

Also developed prior to the start of the unit, were graphic organizers to help students understand concepts (attributes and examples) and an end-of-unit label test and production task(s) based on the concepts and principles identified by the teachers as crucial for student learning. The test incorporated fact-based questions and production tasks with specific questions for higher-order and problem solving thinking skills that included prediction, evaluation, and application questions. The production task section was made up from a combination of either a graphic essay, written essay, and/or interview. After students had completed both the label test and problem-solving tasks, they were asked to rate their test performance (how well they thought they had done) on a scale of 1 (very poor) to 5 (excellent). We gave them no other prompt to help make this judgment.

Curriculum

The unit was based on a science curriculum published by Hackett, Moyer, and Adams (1989) and included three chapters: "Matter and its Changes," "Combinations of Matter," and Investigating Matter." The study was done with the last chapter, which was comprised of 35 pages complete with readings and activities. The major concepts (see italicized words) included in the test were as follows:

"Pure matter is always the same in composition and is known as a *substance*" (p. 47).

"A *chemical property* is one that relates to how a substance changes to a new substance" (p. 48)...A *chemical change* is the formation of a new substance with different chemical properties" (p. 49).

"A *physical property* is one that can be observed without referring to another substance" (p. 51)...A *physical change* is a process that does not change the chemical composition of a substance" (p. 52).

"All matter is made of tiny particles called *atoms*...A substance made of just one kind of atom is an *element*" (p. 54).

"All atoms have a core called the *nucleus*, which contains *protons* and *neutrons*. A *proton* is a particle in an atom that has a positive charge. A *neutron* is a particle in an atom with no electric charge...A particle with a negative electric charge called an *electron* moves around the nucleus...In an atom, the number of positively charged protons equals the number of negatively charged electrons" (p. 55).

"A *compound* is a substance formed when atoms of different elements combine chemically" (p. 67).

"Some atoms share electrons with other atoms forming a particle called a *molecule*...Compounds made of molecules, such as water, are called *molecular compounds*. In molecular compounds, the atoms share electrons" (p. 68).

"An atom that has gained or lost an electron is an *ion*" (p. 69).

"A *mixture* is a combination of substances that forms without a chemical reaction...Mixtures can be combinations of solid, liquid, and gaseous substances" (p. 72).

"A *solution* is a special kind of mixture in which a substance is spread evenly throughout another substance. A solution is exactly the same all the way through" (p. 73).

"A *saturated solution* is a solution in which no more of a substance can be dissolved at that temperature" (p. 73).

"A *suspension* is another kind of mixture in which the substances that make it up are not dissolved...Substances in a mixture are not chemically combined. Each substance still has its own properties. The physical properties of substances can be used to separate mixtures." (p. 75).

<u>Instruction</u>

Instruction consisted of initially demonstrating the properties of atoms, reading the text and discussing the ideas, conducting individual and group activities focusing on acid/base indicators, implementing experiments, assigning worksheets from the text, giving students crossword puzzles for vocabulary study, using graphic organizers, flow charts and diagrams in lectures to show how compounds are sorted, and finally, reviewing the unit using a panel of experts or jeopardy games.

<u>Data Collection and Analysis</u>

The test was analyzed by taking all items that addressed a specific concept and totaling the values to achieve a subtotal for each student, which was then averaged across all four classrooms. At the end of the unit, teachers assembled as a group and completed three activities.

First, in an interview/survey, they answered three process questions: (a) how do you normally construct a test? (b) how different was this unit from what you normally do? and (c) how did the unit curriculum and test provide sufficient opportunity to learn?

Second, they scored the tests. In the scoring process, they initially reviewed the short answer problem-solving questions on the test and discussed the general qualities of a "good" answer and then they went through all the tests, surveying them in general. Next, they sorted (within each classroom) the test protocols into three piles (high, middle, and low); sorting the middle pile a second time into a high and a low to achieve a 4-point scale. Finally, they identified the high responses and a "just passing" response, describing why they thought it was high or barely adequate. An analysis of the reliability of three problem-solving questions that were most highly related to the identified concepts (numbers 15, 18, and 19) was conducted to determine the amount of agreement achieved in this rating process with the following results: For question 15, 89% agreement was reached on 58 essays; for 56 essays on question number 18, 71% agreement was attained; for question 19, agreement was only 59% on 73 essays.

After the scoring process was completed, they were asked the following outcome questions on an interview/survey: (a) what concepts do you think most students learned? (b) what misconceptions do you think students had and why did they materialize? and (c) what materials and activities were most important in making the concepts and principles concrete and helped the student learn?

Results

Generally, students averaged slightly more than half the points possible: (a) for the total objective items (1-12), students averaged 58% correct, (b) the essay total averaged 53% of the possible points, and (c) total test performance averaged 54% of the total number of points. The highest performing students were talented and gifted (TAG), followed by general education students or students being served in Title 1 and the lowest performers were receiving special education. On the labeling total, essay total, and the total test, these differences were significant, therefore Scheffe's test for differences between pairwise combinations of groups was conducted. For the fact label totals, TAG students were significantly higher than general or special education students, but not Title 1 students. On the problem essay, the only differences between groups that was <u>not</u> significant was between general education and Title 1 students. Finally, on the total test, TAG students significantly outperformed everyone and general education students were significantly higher than students receiving special education. See Table 2 for means and significance values.

The remaining analyses are presented for individual concept totals. See Table 3 for the outcomes of each concept problem-by-measurement format. Analyses of two important concepts (mixture and matter) are presented in Tables 4 and 5, for both objective and problem-solving formats. In Table 4, the concept *mixture* is analyzed with frequency distributions of scores; a rather platykurtic curve appears for both measurement formats. The relationship between them, however, is significant. In Table 5, the same analyses are presented for the concept *matter*; again, a rather platykurtic distribution results with a significant relationship between the two measurement formats.

In Table 6, the intercorrelation among the various concept totals is displayed. In general, the various performance estimates for these concept totals were quite moderately to highly related to each other. The differences in size of relationship was negligible between the objective and essay formats: Concepts appeared equally highly related to each other across the same formats and these correlations were about the same as those between different concepts within the same format. Of course, each of the concept totals was most highly related to the subtotal (for objective and essay) and total test values. See Table 6.

Not only was the test generally quite difficult, but the first part of the test, which included 12 items requiring students to match vocabulary words with the correct factual definition, had a high percentage of misconceptions. In this table each concept label is listed in the leftmost column and then the most frequently chosen concept selected incorrectly as the answer is presented, with both the count of students who chose that incorrect concept as well the percentage of students, relative to all the students who answered it incorrectly. This same analysis is presented for the second most frequently chosen concept selected incorrectly, again with both the count and percentage of students responding. Although no obvious pattern was evident for all the items, a few striking inconsistencies occurred. For example, for *hydrocarbon*, 30% of the students who answered it incorrectly by labeling it with the *ions* definition and 20% labeled it with the *oxide* definition; likewise, for *ions*, 30% labeled it with the *hydrocarbon* definition and 20% with the *solution* definitions. In general, *Ions* and *hydrocarbons* were equally misapplied to each other; furthermore, students had difficulty correctly distinguishing *solution, suspension, saturated* and, to a certain degree, *indicator*.. Finally, *molecule* and *mixture* frequently were mismatched to each other. See Table 7.

These mismatches on the labeling could generally be crosswalked to student performance on the essay problems, though their misconceptions were neither obvious nor inhibitive of (moderately) successful performance. See Table 8. Student responses to the problem-solving appeared to move beyond the poor performance on the label-matching items and embed enough understanding that teachers evaluated their work as having mastered the content. Although on two concepts (*matter and mixture*) the association between performance on the label and performance on the essay was significant, the actual level of association was not always strong. The degree of association for the concept *matter* was quite high (with an odds ratio of 4.7); nevertheless, 40 students could successfully draw an atom with all component parts (score of 5-10 points) but were incorrect in defining matter (scored 0-2 points). For the concept *mixture*, the degree of association was strong only for one pair of labels and essay matches. Little to no association was found for fact item 10 (label of mixture that can be separated by gravity) and essay problem 18 (give an example of a mixture and explain how you would separate it), with an odds ratio of 1.36. Fully half the students not passing the essay problem had correctly labeled the mixture item and nearly as many had incorrectly labeled mixture, but then passed the essay problem. In contrast, a very strong association was found for item 11 (label of a solution in which no more can be dissolved) and essay problem 17 (Prompt: If you add Nestle's quick to milk and stirred until no more will dissolve, what kind of solution has been formed? Now, predict what you would need to do to make more mix dissolve). For this pair of problems, the false positives came from correctly labeling mixture but then failing the essay, with few students incorrectly labeling it but then successfully solving the essay. See Tables 4, 5, and 6 for distributions of scores on concepts (*matter and mixture*) and their relationships.

The final two analyses focused on student self-evaluations. Students' science grades have been plotted along with students' self-evaluations in Figure 1. Two striking findings appeared in our analysis of student perceptions. First, the relationship between student self-perception and their actual performance on the test is moderately high for the problem essays and much lower for factual labels. Second, although a significant proportion of students did poorly in science (received a grade of C or lower), their perceptions of performance were somewhat negatively skewed, with fully 49% of them evaluating their performance as “very good” or “excellent." See Table 9 and Figure 1.

The results of our interview questions asked of teachers at the end of the scoring session have been summarized anecdotally. First, we summarize their reactions to the process of teaching and learning this unit, then we present their judgments of response quality and essay scoring by noting how they valued the responses, and finally we consider their reflections to the unit overall, what was learned, left to learn, and why.

The answers to the three process questions we asked about the unit (how they construct tests, how different this one was, and how much opportunity to learn was provided by the unit materials, curriculum and test) revealed generally similar responses across the three teachers. All three teachers indicated that they generally used the textbook to define the goal of the unit and the learning outcome (test content and format); no one created their own test. They also responded that the process of creating a conceptual roadmap for the unit was very different, allowing them to create a test that emphasized what they wanted the students to learn; also the use of graphic organizers was viewed as very helpful in both framing and reviewing the concepts. They also noted that this was the first time they were asking questions requiring involved answers. Finally, the test appeared more encompassing by asking fact (labeling), drawing, and problem-solving questions; they all thought the test did a good job of reflecting students' abilities and skills, though more time and more hands-on activities would be useful in furthering what students learned.

For Question 15 (providing examples in the kitchen of a chemical and physical change), the key to a high response was giving good examples and thorough explanations why; an adequate response provided one but not the other. For question 18 (providing an example of a mixture and how to separate it), to obtain a high rating, the critical issue was use of the term evaporation and description of how to separate; an adequate response was correct but without an explanation of separation. Question 19 (the difference between organic and inorganic compounds and illustrations), the key to obtaining a high rating was to provide a correct definition and giving examples; an adequate response was lacking in examples.

When asked what was learned, what misconceptions were still present, and what was important in the learning process, generally similar responses were reflected across the three teachers. All three teachers thought that the concepts of organic and inorganic compounds were learned (mastered) and that the atomic structure (diagram of the atom) was learned (mastered). Two teachers thought students were firm on the difference between physical and chemical properties and that mixtures and solutions were learned (mastered). Two teachers thought that the structure of the atom and its classification into the periodic table was most misconceptualized; one teacher believed students were confused yet about the vocabulary. Finally, one teacher thought that students were still confused about chemical and physical properties. When asked about the importance of various teaching support systems to facilitate learning, the most important components for all three teachers were the hands-on activities and models and diagrams.

Discussion

The results of this study begin to clarify the relationship between science benchmarks and the attempts of teachers to operationalize those benchmarks into curriculum adaptations and assessment of learning using both factual and problem-solving questions. From this study, it seems that teachers have little trouble revising their curricula to highlight important concepts and principles and incorporate them into problem-solving tasks. The teachers who participated in this study and the authors of science benchmarks and standards use similar language when valuing the instructional domains and learning outcomes. For example, consider the language of the American Association for the Advancement of Science (AAAS, 1993) benchmark and an important concept that teachers identified:

- "All matter is made of atoms, which are far too small to see directly through a microscope. The atoms of any elements are alike but are different from atoms of other elements" (AAAS, p. 78).
- "All matter is made of tiny particles called *atoms*...A substance made of just one kind of atom is an *element*" (Hackett, Moyer, & Adams, 1989, p. 54).

All three teachers had identified this concept as important in the two prior chapters and used it to further explicate the concepts of compounds (organic and inorganic), mixtures, and solutions. They, then, taught to these concepts using a variety of strategies (models and demonstrations as well as readings and discussions). Furthermore, once the goals and curricula were articulated around these concepts, assessment items were crafted to reflect diversity of knowledge forms (declarative versus procedural-declarative). The teachers who participated in this study easily developed assessment items designed to measure student mastery of the concepts, principles, and problem-solving processes. In the end however, they were somewhat uncertain of how well students had learned some of the concepts, given the abstract nature of the elements of atoms.

In general, students did not master unequivocally, the concepts targeted by the teachers. Performance was quite low across most of the concepts for both components of the test, the fact labeling and the problem-solving essay. Often, the average was half the total possible. It may be that the national (international studies United States Department of Education, 1992, 1993) are correct in placing American students quite low in performance relative to other industrialized countries. If this is true, the benchmarks identified by Project 2061 need to be more than simply goals for attainment, but used to reform classrooms. In the classrooms participating in this study, instruction, though well designed and executed, simply failed to prepare students for understanding many important concepts of matter, either in knowing specific words (concepts) using definitions or in using the words (concepts) to solve problems.

This poor performance was ubiquitous and was not differential according to knowledge form (declarative versus procedural-conditional). For example, though we have used the terms separately as if they represent unique constructs (Alexander, Schallert, & Hare, 1991), the pattern of responding on the test showed considerable blur among them, even when the knowledge forms were analyzed within (as well as across) concepts. The odds ratios (Fleiss, 1981) were high in explaining the cross-tabulation of fact (label) by problem-solving (essay) for two concepts, mixture and matter, indicating a significant relationship. These ratios reflect the statistical significance of probabilities of an antecedent event being followed by a consequent event. Clearly, on important concepts, the earlier matching of a concept label with its definition is predictive of later successful answers to problem-solving tasks. Furthermore, moderately high correlations were found between the fact questions of several concepts (i.e., compounds, inorganic compounds, and mixtures) and problem-solving essays. Nickerson (1985) may well be correct in his assertion that the more knowledge one has about a concept, the greater their understanding.

Additional caveats are warranted in the area of test construction which may limit this study. Careful attempts were made to create factual and problem-solving items that hinged on a single concept. However, the construction of items intended to focus on a single concept. However, some prompts and certainly many answers contain more than a single concept, and therefore, it may be difficult to attribute item difficulty to a single concept. Similarly, because so few items contributed to each item analysis by concept, our conclusions need to be tempered. Finally, on one of the problem-solving questions, teachers were not as reliable as we would have wanted them to be. Nevertheless, we also required agreement to be an exact match and if we had allowed them to disagree by one point, this figure would be nearly 100% for each of the essays.

These shortcomings in test construction would suggest that it may be difficult to detect associations between concept mastery and achievement on either the fact labels and short answer problems-solving essays. Yet, student performance on one concept, *compounds*, was strongly related to student performance on both labels and problem-solving essays and was strongly related to student self-evaluation (r_{yy} = .92 - .93). This strong correlation indicates that there may be a 'big idea' indicative of mastery of this domain; when students performed well on items that dealt with *compounds*, the students performed well on factual items as well as other problem-solving items measures, and were more accurate in their self-evaluations.

In the end, the results of the two measurement formats (fact labels and short answer problems-solving essay) remained disjointed for the teachers. Although they thought students had mastered some of the concepts, they were not correct in their judgments. This outcome may be a function of teachers neither summarizing item difficulties of the label-matching items nor connecting them with performance on the problem-solving task (using either a cross-tabulation or correlation). It was as if the teachers could not reconcile two different systems for gauging student performance. The teachers had taken steps toward a more systemically valid assessment, but meandered in the evaluation stage.

Finally, students reflected considerable misconceptions about the concept labels and yet, these misconceptions only partially explained performance on the problem-solving tasks. Although relationships among the two measurement formats was considerable and significant, in fact, many students performed well on one type of task and poorly on the other, or visa versa. Certainly, we cannot rely upon student judgment, however, in determining whether they have achieved mastery; not only were their judgments inflated but their science grades were unrelated to performance in this particular test, probably because of the reliance upon effort and homework completion that influences grades but is masked in test performance.

Therefore, at the individual student level, a careful analysis needs to be conducted before moving on to successive units. The most significant limitation may be that teachers used the outcome data summatively, not formatively, as suggested by the findings of Guzzetti et al. (1993). A very positive outcome may have been achieved had teachers given the test, analyzed it for the concepts most mislabeled and misconceived, and then provided both positive and negative examples of their use in solving problems. Under these conditions, attainment of benchmarks may have been possible.

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Author Note

Dr. Gerald Tindal and Jennifer McCleery are with Behavioral Research and Teaching, University of Oregon.

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This project was completed with the assistance of Denise Swanson who managed the data coding, entry, and organization. The teachers involved in this project are to be commended for their participation in the project and diligence in developing and analyzing student performance measures.

Correspondence for this article should be addressed to: Gerald Tindal, Behavioral Research and Teaching, BRT-232 Education, University of Oregon, Eugene, Oregon 97403-5262. Electronic mail may be sent to: geraldt@darkwing.uoregon.edu.

Table 1.

Descriptive Statistics for Participating Students

Variable	Count	Percent
Educational Status		
Chapter 1	10	11.0
Gen Ed	61	67.0
Spec Ed	11	12.1
Tal & Gift	9	9.9
Total	91	100.0
Ethnicity		
A/A	4	5.0
A/P	3	3.8
H	1	1.3
W	71	89.9
Total	79	100.0
Gender		
F	49	53.8
M	42	46.2
Total	91	100.0
Science Grade (Trimester)		
A	10	13.5
B	17	23.0
C	26	35.1
D	17	23.0
NP	1	1.4
P	3	4.1
Total	74	100.0

Cont Var:	TriAbs	YrAbs	TriGPA	GPA	MTotSS	MTotPR	RTotSS	RTotPR	TotSS	TotPR
Mean	3.4	26.9	2.7	2.8	220.9	58.7	216.0	46.0	437.9	55.5
Std. Dev.	3.5	161.9	.8	.8	11.3	27.5	10.9	27.6	21.7	27.6
Std. Error	.4	17.2	.1	.1	1.3	3.2	1.3	3.2	2.5	3.2
Count	78.0	89.0	78.0	78.0	76.0	76.0	76.0	76.0	76.0	76.0
Minimum	0.0	0.0	1.1	1.2	200.0	5.0	191.0	1.0	393.0	3.0
Maximum	14.5	1535.0	4.0	4.0	264.0	99.0	247.0	99.0	504.0	99.0
# Missing	13.0	2.0	13.0	13.0	15.0	15.0	15.0	15.0	15.0	15.0

TriAbs = trimester absences
YrAbs = year absences
GPA = year GPA
MTotSS = math total standard score, Oregon Statewide Achievement Test
MTotPR = math percentile rank, Oregon Statewide Achievement Test
RTotSS = reading total standard score, Oregon Statewide Achievement Test
RTotPR = reading percentile rank, Oregon Statewide Achievement Test
TotSS = total standard score
TotPR = total percentile rank

Table 2.

Differences Among Groups of Students on Fact Labeling, Problem Essay, and Total Test Performance

Fact Label Total (F=5.9 (3,87 df), p=.0011)

	Count	Mean	Std. Dev.	Std. Err.
Title 1	10	.667	.312	.099
General Ed	61	.631	.276	.035
Special Ed	11	.515	.396	.119
Talented/Gifted	9	1.019	.100	.033

Problem Essay Total (F=13.3 (3,87 df], p<.0001)

	Count	Mean	Std. Dev.	Std. Err.
Title 1	10	.412	.217	.069
General Ed	61	.418	.188	.024
Special Ed	11	.174	.147	.044
Talented/Gifted	9	.697	.074	.025

Total Test (F=13.2 [3,87df], p<.0001)

	Count	Mean	Std. Dev.	Std. Err.
Title 1	10	.463	.215	.068
General Ed	61	.461	.189	.024
Special Ed	11	.242	.184	.056
Talented/Gifted	9	.761	.068	.023

Table 3.

Descriptive Statistics for Concept Subtotals (Fact Label and Problem Essay) on Science Posttest

Concept	Mean	Std. Dev.	Std. Error	Count	Min	Max
Compounds-Fact (5 points)	2.78	1.74	.18	91	0	5
Compounds-Prob (16 points)	7.71	5.12	.54	91	0	16
Inorganic Compounds-Fact (3 points)	1.97	1.06	.11	91	0	3
Mixture-Fact (4 points)	2.17	1.46	.15	91	0	4
Mixture-Prob (8 points)	4.62	2.94	.31	91	0	8
Mixture-Prob (14 points)	7.63	3.89	.41	91	0	14
Total Test-Prob (38 points)	19.95	10.34	1.08	91	0	38
Total Test-Fact (12 points)	6.91	3.70	.39	91	0	12
Total Test (50 points)	26.86	13.07	1.37	91	1	50

Table 4.

Frequency Distribution for Combined Fact Label and Problem Essay Evaluations to Questions Focused on "Mixture"

Factual-Score	Count	Percent
0	17	18.68
1	15	16.48
2	18	19.78
3	18	19.78
4	23	25.27
Total	91	100.00

Essay-Score	Count	Percent
0	13	14.29
1	5	5.49
2	10	10.99
3	6	6.59
4	7	7.69
5	8	8.79
6	10	10.99
7	7	7.69
8	25	27.47
Total	91	100.00

	Problem Essay									
Fact	0	1	2	3	4	5	6	7	8	Totals
0	5	2	2	2	2	1	2	0	1	17
1	3	1	3	1	0	0	3	2	2	15
2	2	0	1	1	5	0	4	2	3	18
3	3	1	3	1	0	4	1	1	4	18
4	0	1	1	1	0	3	0	2	15	23
Tot	13	5	10	6	7	8	10	7	25	91

χ^2 (32, N = 91) = 59.6, $p < .01$

Table 5.

Frequency Distribution for Two Problem Essay Evaluations to Questions Focused on "Matter"

Score (#13)	Count	Percent
0	8	8.79
1	2	2.20
2	4	4.40
3	9	9.89
4	7	7.69
5	7	7.69
6	9	9.89
7	7	7.69
8	16	17.58
9	14	15.39
10	8	8.79
Total	91	100.00

Score (#14)	Count	Percent
0	20	21.98
1	26	28.57
2	21	23.08
3	8	8.79
4	16	17.58
Total	91	100.00

		Problem Essay Question # 14*				
Essay #13*	Total	0	1	2	3	4
0	8	7	0	0	0	1
1	2	2	0	0	0	0
2	4	2	1	0	1	0
3	9	4	3	2	0	0
4	7	1	3	2	1	0
5	7	0	4	2	1	0
6	9	1	1	3	0	4
7	7	0	2	2	3	0
8	16	2	4	7	1	2
9	14	0	8	2	1	3
10	8	1	0	1	0	6
Total	91	20	26	21	8	16

$\chi^2 = (40, \underline{N} = 91) = 92.7, p<.0001$

*Odds ratio (o) = 4.7, s.e. (o) = 2.08 with 5-10 points passing problem 13 and 3-4 points for problem 14.

Table 6.

Correlation Matrix for Concept Subtotals on Science Posttest

Concept	2	3	4	5	6	7	8	9
1-Compounds-Fact Label	.588	.652	.676	.497	.504	.623	.925	.754
2-Compounds-Prob Essay		.539	.402	.571	.731	.918	.590	.893
3-Inorganic Compounds-Fact Label			.501	.510	.471	.595	.791	.694
4-Mixture-Fact Label				.457	.436	.496	.856	.634
5-Mixture-Prob Essay					.527	.809	.560	.798
6-Mixture-Prob Essay						.845	.545	.822
7-Total-Prob Essay							.659	.977
8-Total-Fact Label								.804
9-Total								

91 observations were used in this computation.
15 cases were omitted due to missing values.

Table 7.

Fequency Count of Incorrect Concepts on Science Posttest

Correct Concept	Most Frequent Incorrect Concept[1]			Second Most Frequent Incorrect Concept[1]		
	Concept	No.	Prcnt	Concept	No.	Prcnt
1. Hydrocarbon	Ions	12	30	Oxide	8	20
2. Ions	Hydrocarbon	12	30	Solution	7	20
3. Compound	Molecule	11	25	Mixture	10	23
4. Inorganic Compound	Saturated	3	20	Ions	3	20
5. Molecule	Compound	16	32	Mixture	10	20
6. Oxide	Molecule	8	24	Mixture	5	15
				Solution	4	12
7. Mixture	Molecule	7	16	Saturated	5	12
	Oxide	6	14	Neut. Cmpnd.	5	12
8. Neutral compound	Hydrocarbon	7	27	Molecule	4	15
				Indicator	4	15
9. Indicator	Solution	5	21	Suspension	5	21
10. Suspension	Solution	14	33	Saturated	5	12
11. Saturated	Suspension	11	39	Mixture	5	18
12. Solution	Suspension	11	26	Compound	6	14
				Ions	5	12

[1]When an answer is incorrect, the number and percentage of times that students selected the concepts listed in these column. Percentages of each concept are relative to the total number of incorrect answers for the item; therefore, the most and second most frequent incorrect concepts may not total 100 because other incorrect concepts may have been listed.

Table 8.

Cross-Product Ratio for Four Questions Addressing "Mixture" with Row Percentages

Facts Item 10 — Essay Problem 18

	Pass (3-4)	Not Pass (0-2)	Margin Total
Correct (1)	22 (51%)	21 (49%)	43
Incorrect (0)	20 (43%)	26 (57%)	46
Margin Total	42 (47%)	47 (53%)	89

Odds ratio (o) = 1.36, s.e. (o)=.578

Facts Item 11 — Essay Problem 17

	Pass (3-4)	Not Pass (0-2)	Margin Total
Correct (1)	39 (65%)	21 (35%)	60
Incorrect (0)	3 (10%)	26 (90%)	29
Margin Total	42 (47%)	47 (53%)	89

Odds ratio (o) = 16.09, s.e. (o)=7.16

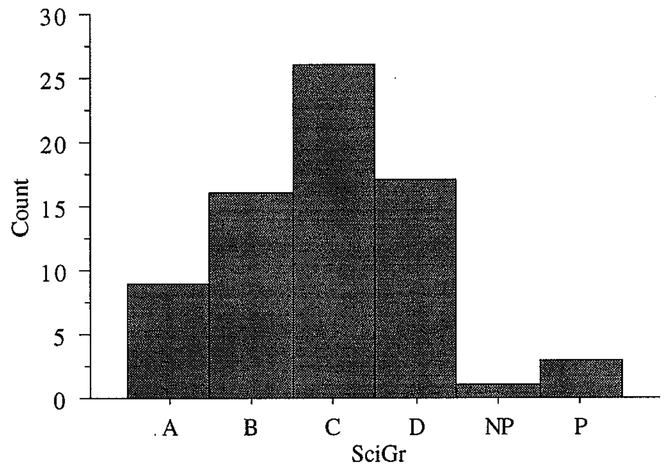
Table 9.

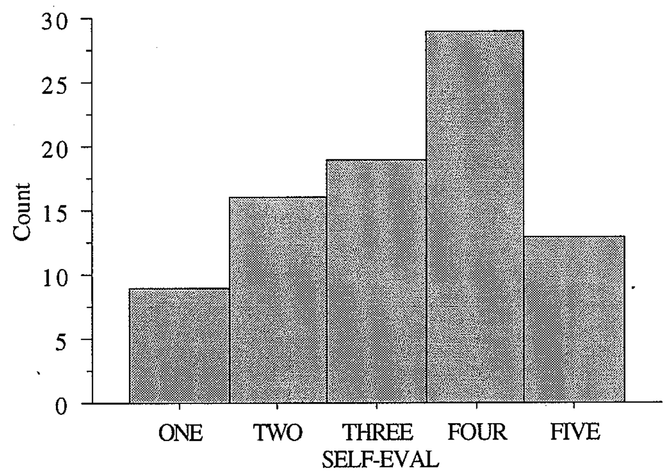
Descriptive Statistics of Student Self Evaluations and its Relationship with Test Performance

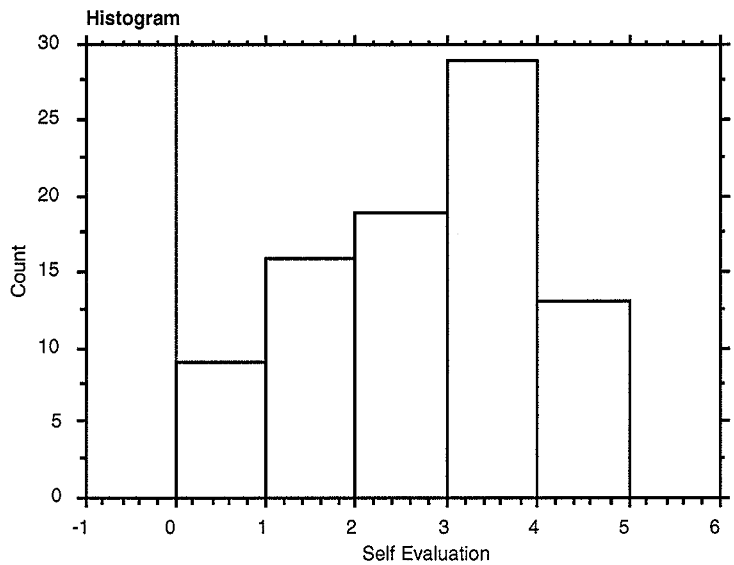
	Self Evaluation
Matter-Essay	.33
Compunds-Essay	.56
Inorganic-Fact	.29
Compunds-Fact	.29
Total Fact	.31
Total Essay	.54
Total Test	.52

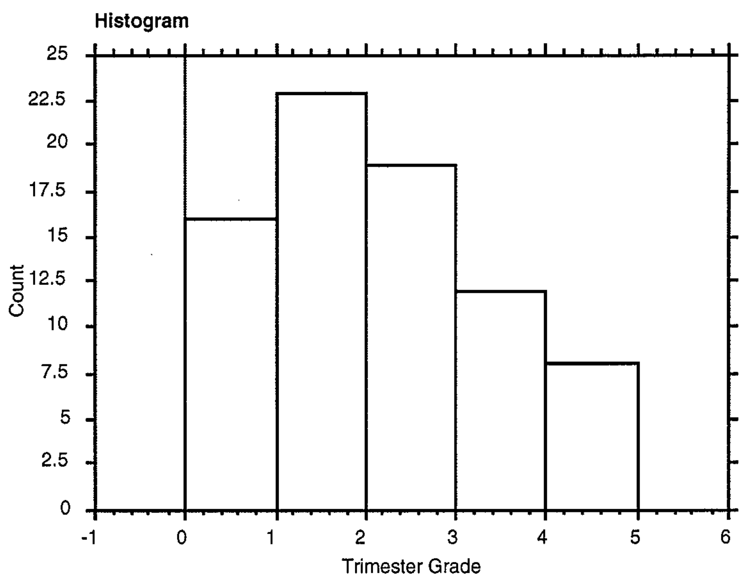
Figure Captions

Figure 1. Distibution of teacher grades and student self evaluations.









Key	<u>Self-Evaluation</u>	<u>Trimester</u>
	5 = Excellent	A = 4
	4 = Very good	B = 3
	3 = Average	C or P = 2
	2 = Below avgerage	D = 1
	1 = Unacceptable	F or NP = 0

6th Grade Science

Text Unit 2, Interactions of Matter, including Chapters 3, 4, and 5, Matter and it's Changes, Combinations of Matter, and Investigating Compounds.

Chapter 3 (Concept Organization Form includes "Matter")

Chapter three presents atomic theory, physical states of matter, the periotic table, elements, chemical properties and chemical reactions. The broad base of information serves as a foundation for the two following chapters in the unit.

Matter is described as anything that has mass and takes up space. A discussion of the classification of matter begins with the physical states of matter, and definitions for the words 'substance' and 'chemical properties'.

Chemical reactions and chemical changes are defined and illustrated, and the law of coservation of mass is presentented. Energy is mentioned in relation to chemical changes as being either released or absorbed in the form of light, heat, or electricity.

The concept of physical properties is defined. It is noted that physical changes do not change the chemical composition of substances. A lesson summary includes the following concepts as central: substances are pure; chemical properties depend on chemical reacion behavior; conservation of mass; physical properties.

The composition of substances is the heading for a discussion of atoms, atomic structure, and elements. Examples of elements are presented.

Atomic structure is outlined including nucleus, neutrons protons and electrons. Atomic number is defined. Electrons are described. The lesson summary outlines the following important concepts; all matter compossed of atoms; different elements are composed of different atoms; neutrons have no charge; protons have a possitive charge and electrons have a negative charge.

The classification of elements in the periotic table is discussed in terms of organization by atomic number. The text notes that elements with similar arrangements of electrons are are grouped together into families. Metals and nonmetals are compared in terms of location on the periotic table and physical properties. The final lesson summary lists the following concepts as important: the periodic table; symbols represent elements; elements are classified as metals or nonmetals according to electron structure.

Activities for the chapter include observing the properties of an apple and an electron cloud model. The chapter ends with a language arts skills exercise on deriving the meaning of unfamiliar words.

The visual aids used in the chapter include: pictures of written words and music to help define 'composition'; picture of a garden being watered; pictures of chemical reactions; photograph depicting the production of an apple pie; picture of a park bench; photograghs of the three states of water; photographs showing the assembly of a model airplane; picture of a brick building; pictures likening an atomic model to a fan; photographs of elements at room temperature; the periodic table, a table of substances and their uses; a table of common natural elements.

Chapter 4 (Content Organizaztion Form mentions "Mixtures")

Compounds are introduced in a discussion of atoms, molecules and the formation of molecular compounds. Ions and ionic compounds are also introduced. The rules for writing chemical formulas are outlined. A lesson summary includes the following concepts: the formation of compounds; the differing role electrons play in molecular vs. ionic compounds; and formulas.

Mixtures are discussed incuding solutions, saturated solutions, and suspensions. The separation of mixtures is also adressed. A lesson summary lists the following concepts: mixtures form without chemical reactions; solutions and suspensions are types of mixtures; the separation of mixtures by filtration, evaporation, or settling.

The chapter includes activities with rusting steel wool, dissolving substances in different solvents and the separation of mixtures.

The visual aids for the chapter include: various pictures of sugar and salt (visible and microscopic); depictions of oxygen, carbondioxide and carbonmonoxide molecules; picture of a beach to demonstrate the various types of mixtures; three pictures of sugared glasses of tea demonstrating saturation; a picture of dust as an example of suspension; a picture of a strainer to illustrate a discussion of the separation of mixtures. The chapter ends with a one page essay on polymers.

Chapter 5- (Investigating Compounds)

Chapter 5 outlines the classification of compounds. Organic and inorganic compounds, specifically hydrocarbons, oxides, acids, bases, and salts are discussed in regard to their identifying chemical and physical properties.

A brief history of the distinction between organic and inorganic is presented. Organic compounds are described. Examples and uses of organic compounds are listed, pictured, and briefly discussed. Hydrocarbons, particularly methane, propane and petroleum, are described specifically in regard to structure, formula, and common uses. A lesson summary at the end of the first section reiterates that compounds are classified by physical and chemical properties and that organic compounds contain carbon.

Inorganic compounds are discussed in the context of four groups: oxides, acids, bases, and salts. Each of these is discussed in terms of chemical structure and properties, physical properties and uses. Examples of common forms of each group are pictured throughout this part of the chapter. Acid and base indicators are discussed including litmus paper and phenolphthalein. The lesson summary identifies the following ideas as important: most organic compounds do not contain carbon atoms; oxides, acids, bases, and salts are four kinds of inorganic compounds; indicators are compounds that change color when exposed to acid or base solutions.

A "people and science" vignette about a soil scientist completes the chapter.

Two activities are described using litmus paper and red cabbage juice (respectively) to identify common substances or mystery liquids as acids or bases.

Pictures found in this chapter include the following: a grocery list grouped by category; pictures of common compounds and a note on their composition; pictures of common hydrocarbons; a picture of sand, a common oxide; a picture of acidic foods and a picture of common products containing bases; pictures showing the use of acid and base indicators; and pictures of common products containing salts. Three tables appear in this chapter including "some oxides and their uses", "some inorganic acids and their uses" and "some inorganic bases and their uses."

Teacher Concept Development

Although chapter 3 contains a broad base of information, the teachers developing this unit drew only from the concepts of "matter" and the three states of matter presented in this chapter. Essentially, they felt it was important to emphasize only that everything is composed of matter in one of its three forms.

Similarly, in chapter four, only the concept of "mixture" as "a substance formed but not chemically combined" was retained from a fairly large volume of information.

Finally, in chapter five chemical reactions, organic chemicals and the inorganic families of chemicals were all adopted as concepts central to the unit they developed, thereby utilizing a larger percentage of chapter five material for this unit.

CONTENT ORGANIZATION FORM

Date: 11/4

Teachers:

Class: 6th Science

Textbook: Science, Merrill, Chp. (3-) 5, 82-94

Other Curriculum Materials:

Approximate Schedule of Content to be Delivered

Week	Dates		Textbook Unit	Textbook Chapters	Quiz Dates	Test Dates
1	From: 11/5	To: 11/19	2	(3-)5		
2	From: 11/22	To: 11/24				
3	From: 11/29	To: 12/1				12/1
4	From:	To:				

KEY PRINCIPLES

1. COMPOUNDS
2. INORGANIC
3. ORGANIC
4. MIXTURE
5. MATTER
6.
7.
8.
9.
10.
11.
12.

IMPORTANT IDEAS

1. Chemical compounds are classified according to their composition and properties.

2. All matter changes. Changes can be physical, chemical, and nuclear.

3. Elements in a compound are chemically combined.

CONCEPT DESCRIPTIONS

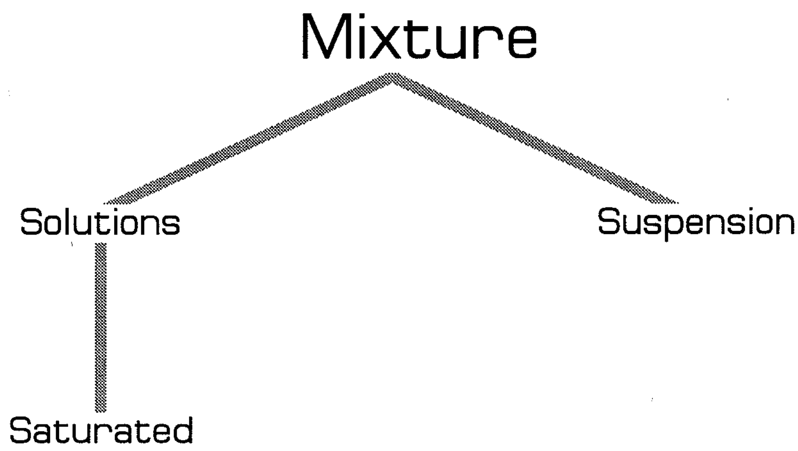
Concept	*Attributes*	Page	*Examples /Nonexamples*	Page
1	Substances combined through chemical reaction/combination.	67	Water molecule, sugars,	67, 68
2	Inorganic: oxides, acids, bases, indicators, salts.	86, 87, 88, 89, 91	Aluminum oxide, silicon dioxide, acetic acid, formic acid, sodium hydroxide baking soda, litmus, phenolphthalein.	
3	Organic: Substances containing C hydrocarbons.	83-85	Vitamins, plastics, methane gas, petroleum.	
4	Mixture: A substance formed but not chemically combined.	72	Fruit salad, air, ocean water, salad dressing.	72-75
5	Matter: Anything that has mass and takes up space, made up of atoms.	47	Person, food, air, water; it can be solid, liquid, or gaseous.	47

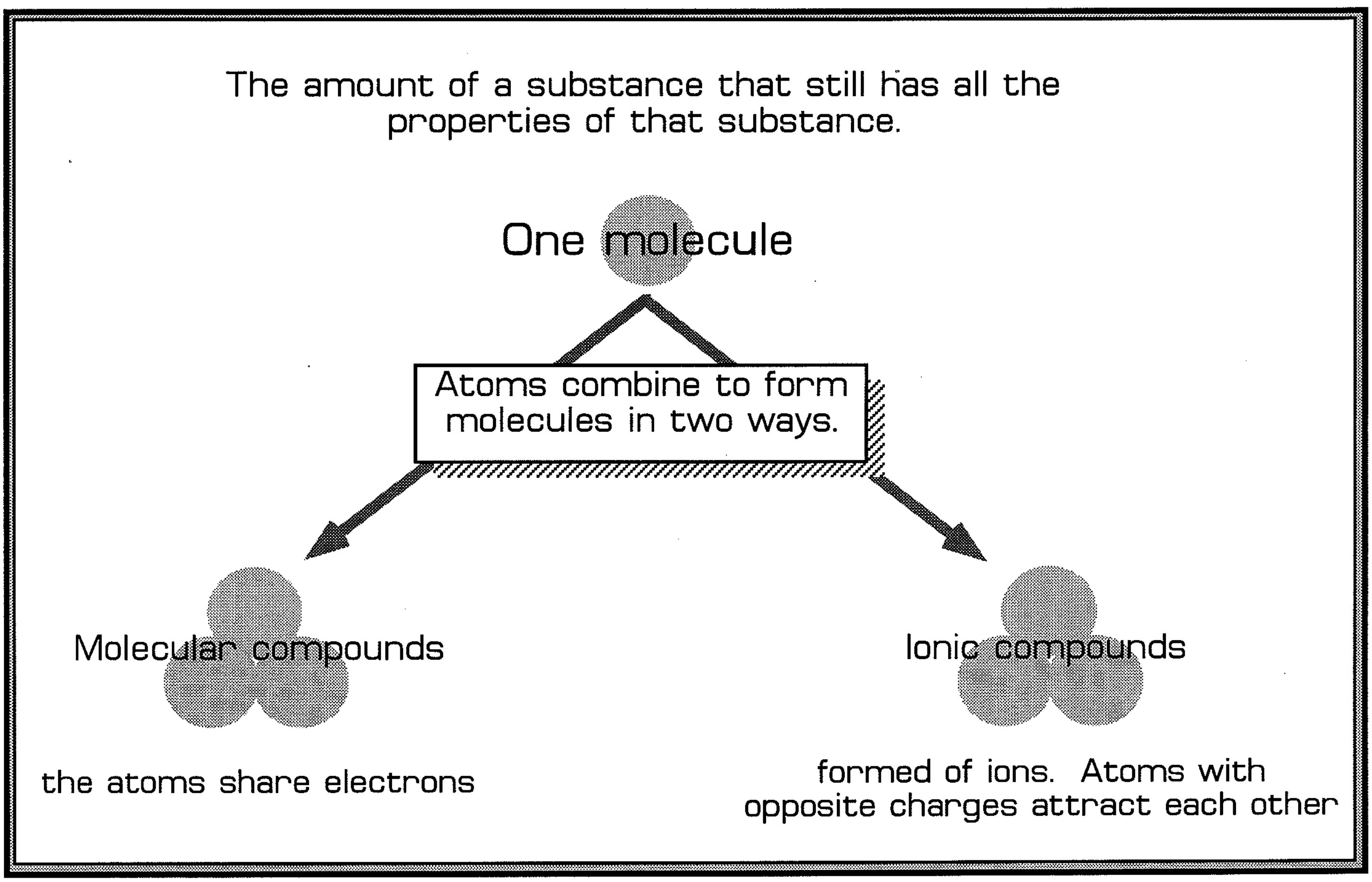
Notes:

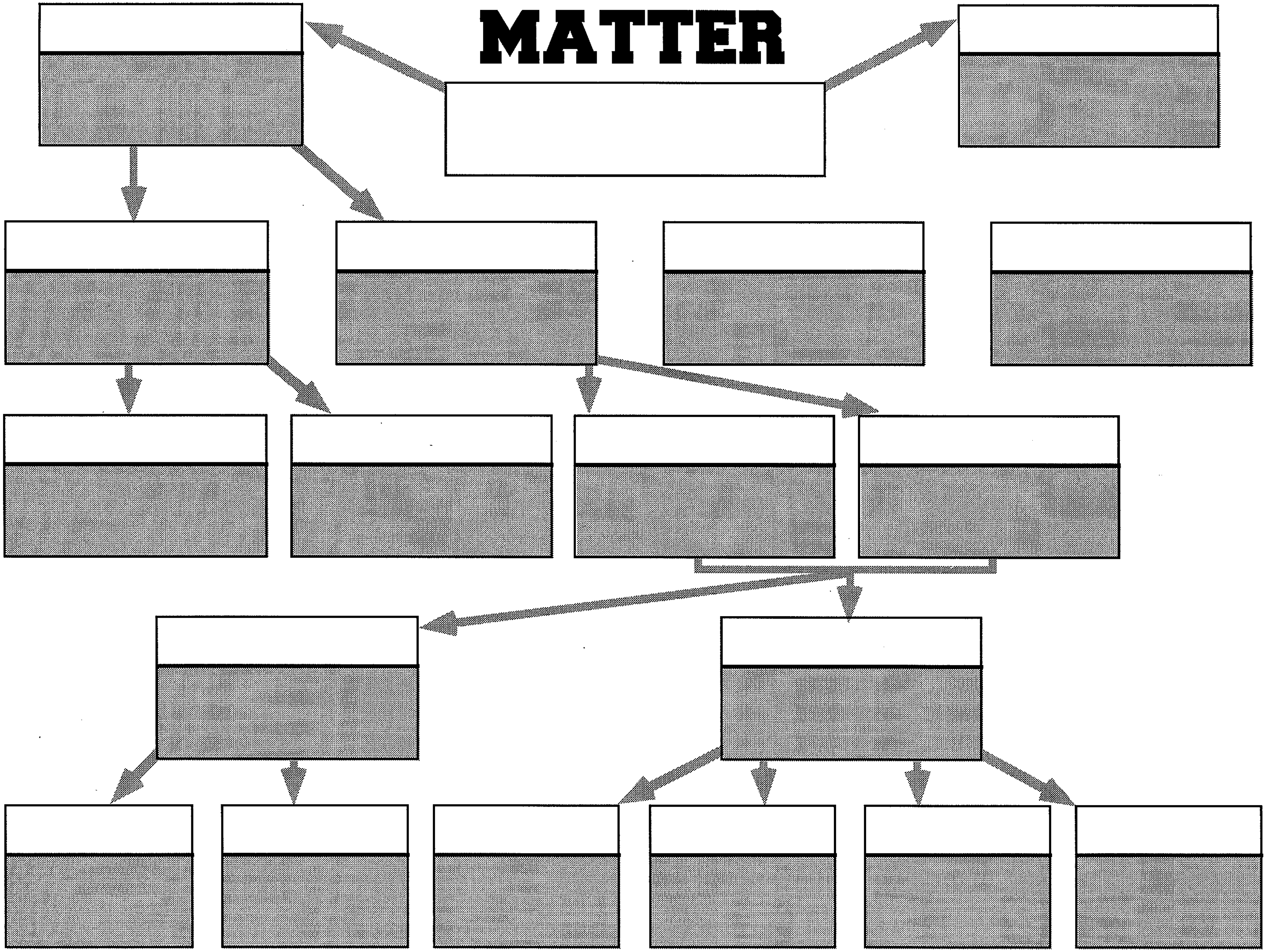
CONCEPT DESCRIPTIONS

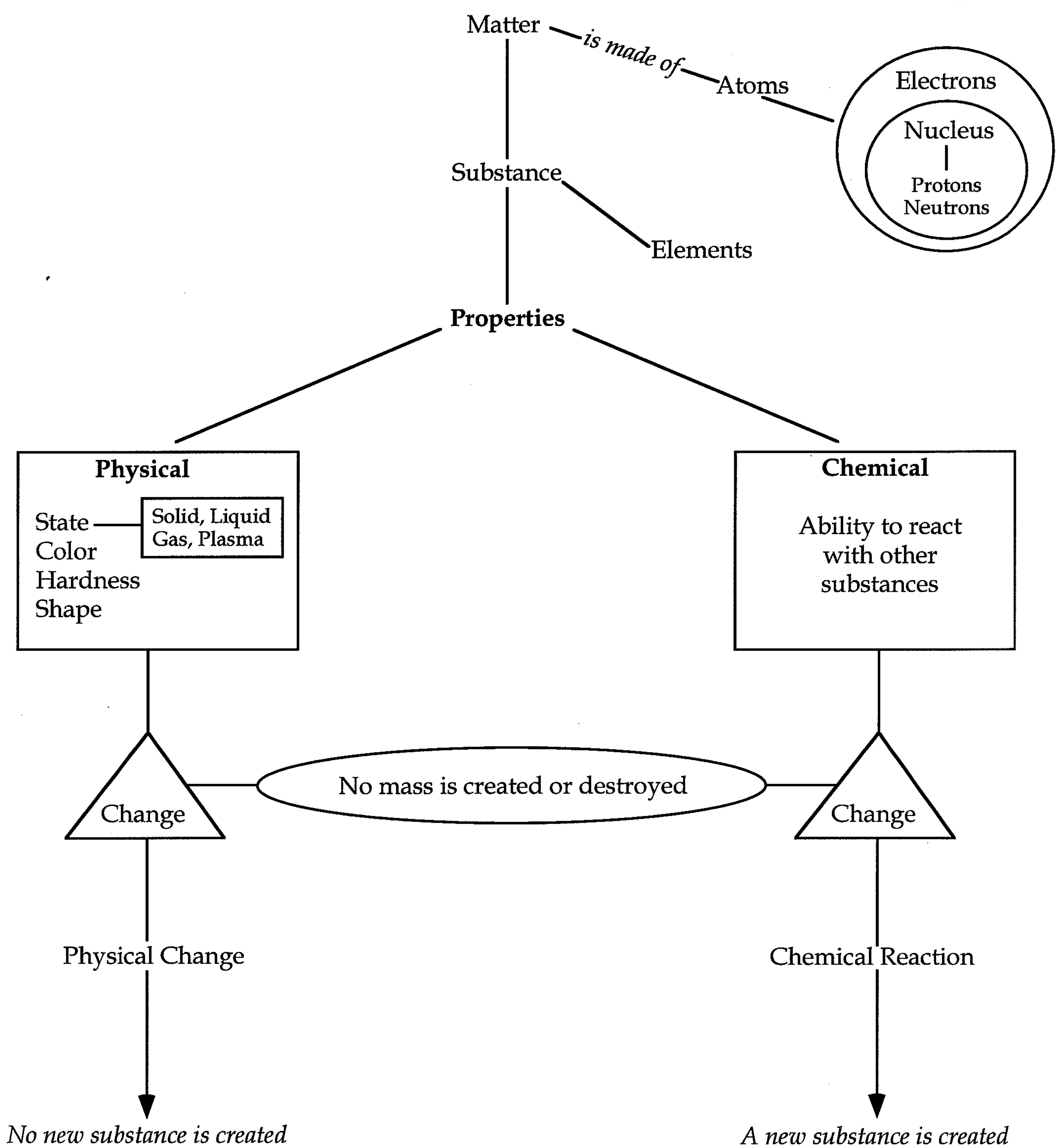
Concept	*Attributes*	Page	*Examples /Nonexamples*	Page

GRAPHIC DISPLAY

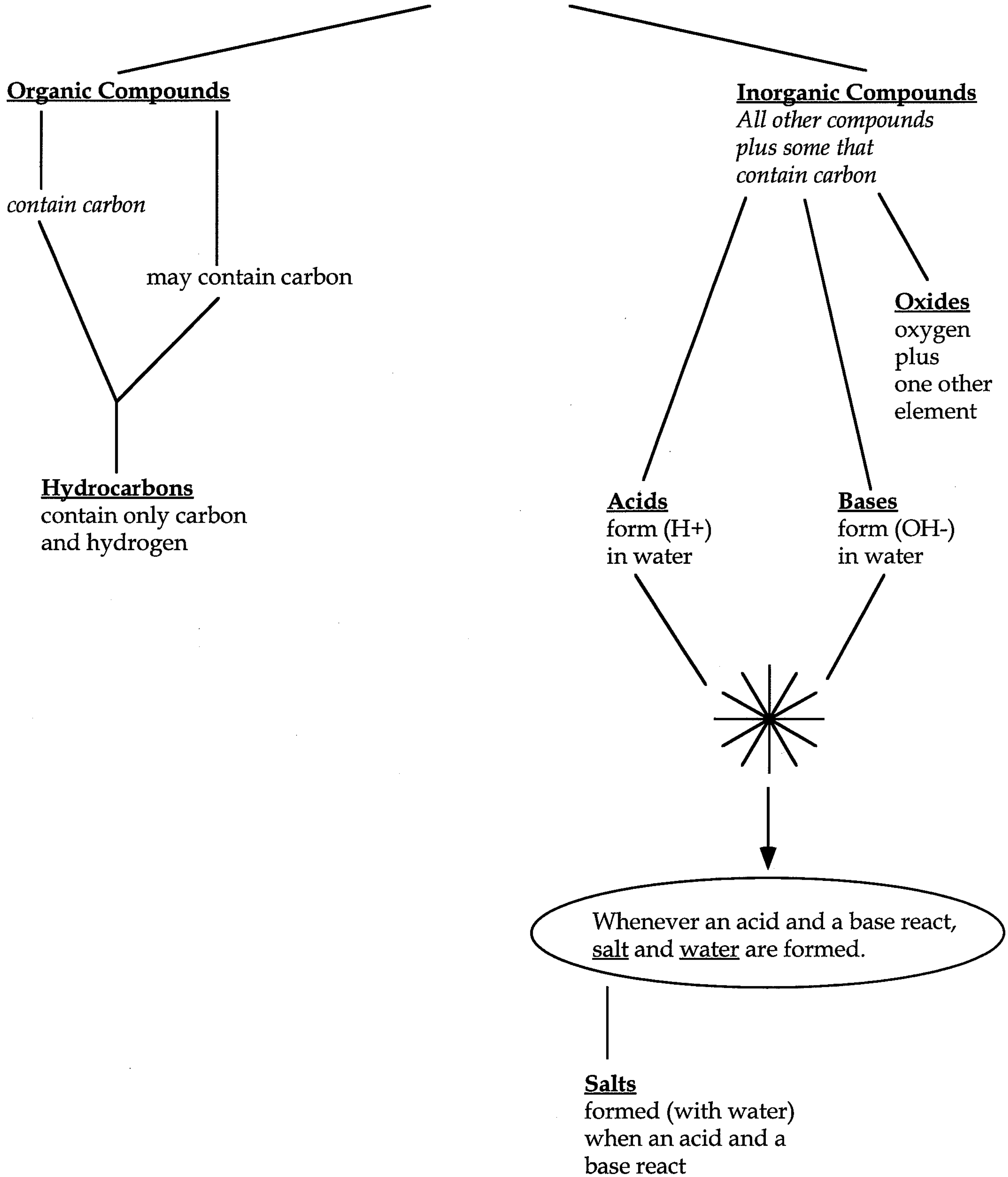

Mixture
Solutions
Suspension
Saturated


The amount of a substance that still has all the properties of that substance.
One molecule
Atoms combine to form molecules in two ways.
Molecular compounds
the atoms share electrons
Ionic compounds
formed of ions. Atoms with opposite charges attract each other


MATTER


Matter
is made of
Atoms
Electrons
Nucleus
Protons
Neutrons
Substance
Elements
Properties
Physical
State
Solid, Liquid
Gas, Plasma
Color
Hardness
Shape
Chemical
Ability to react with other substances
Change
No mass is created or destroyed
Change
Physical Change
Chemical Reaction
No new substance is created
A new substance is created

COMPOUNDS



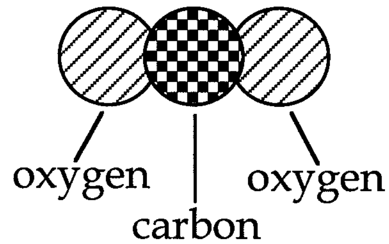
Organic Compounds
contain carbon
may contain carbon
Hydrocarbons
contain only carbon and hydrogen
Inorganic Compounds
All other compounds plus some that contain carbon
Oxides
oxygen plus one other element
Acids
form (H+) in water
Bases
form (OH-) in water
Whenever an acid and a base react, salt and water are formed.
Salts
formed (with water) when an acid and a base react

molecule
smallest particle formed when two or more atoms combine

formula
a group of symbols used to show elements

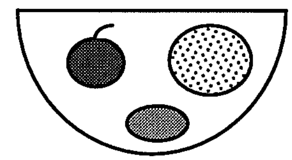
H_2O = water
NaCl = salt

compound
chemical combination of two or more elements



carbon dioxide

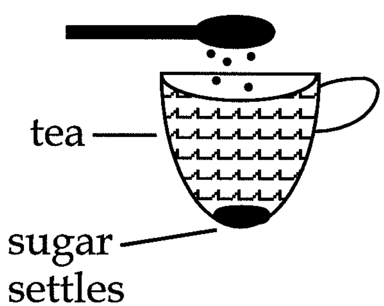
mixture
combination of substances that form without a chemical reaction



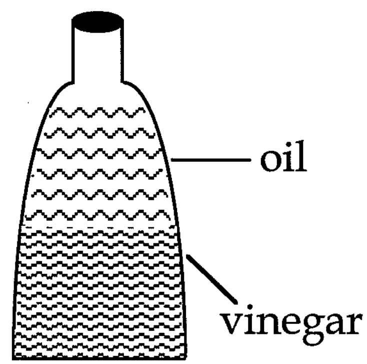
fruit salad

solution
a mixture in which substances are spread evenly

saturated solution
a solution that will dissolve no more substance

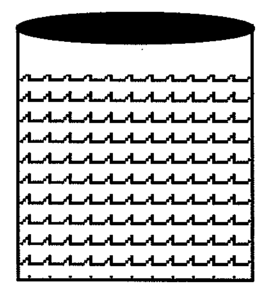


suspension
a mixture in which substances are not dissolved



salad dressing

substance
pure matter, always the same in composition



pure water

INTERACTION OF MATTER
Unit 2 - Final Test

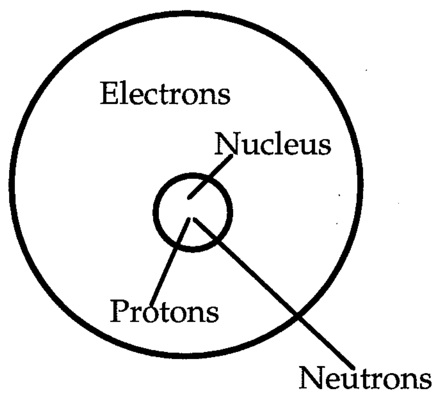
Part 1 - MATCHING

A. SOLUTION	G. OXIDE
B. MIXTURE	H. NEUTRAL COMPOUND
C. SATURATED	I. INDICATOR
D. COMPOUND	J. ION
E. MOLECULE	K. SUSPENSION
F. HYDROCARBON	L. INORGANIC COMPOUND

Concept	*Questions/Answers*	*1 Point each*
Compounds	F 1. Type of compound used to make gasoline, plastics, and paint.	
Inorganic	J 2. Atom that has gained or lost an electron.	
Compounds	D 3. Substance containing elements that are chemically combined.	
I.O. Cmpnds	L 4. Compound that is not organic.	
Compounds	E 5. Combination of two ore more atoms joined by sharing electrons.	
I.O. Cmpnds	G 6. Oxygen combined with one other element.	
Mixture	B 7. Any combination of substances that are NOT chemically combined.	
Compound	H 8. A substance with a pH of 7.	
Compound	I 9. May change color when added to an acid or a base.	
Mixture	K 10. Mixture that can be separated by gravity.	
Mixture	C 11. Solution in which no more can be dissolved.	
Mixture	A 12. Mixture made of dissolved substances.	

Part B - IDENTIFICATION - DRAWING

Concept	*Questions/Answers*	*Pts.*
Matter	13. DRAW, LABEL, AND EXPLAIN THE THREE PARTS OF AN ATOM.	
	A) DRAW & LABEL:	**10**



B) EXPLAIN:

The nucleus is the core or central part of an atom, and it is surrounded by a cloud of electrons. Protons are particles with a positive charge. Neutrons are particles with no charge. Electrons form a cloud around the nucleus, and they have a negative charge. The number of positively charged protons equals the number of negatively charged electrons.

PART 3 - SHORT ANSWER

Concept	***Questions/Answers***	***Pts.***
Matter	14. Give 3 to 5 ways that we classify elements in a periodic table. By atomic structure, similar properties elements with the least amount of mass are at the top of each column, group into metals and nonmetals.	4
Compounds	15. If you are in a kitchen, give an example of a physical and chemical change that could happen and explain your answer. A physical change would be evaporating or boiling water on the stove. That would be a physical change because it only changes state. A chemical change would be baking bread. The yeast reacts with the sugar causing the bread to rise. A chemical change is if bread rises. A physical change is if butter melts.	4
Compounds	16. You are in a forest, give an example of a physical and chemical change that could happen and explain your answer. If a tree fell then that's physical. Chemical is if 2 trees were growing together and atoms of different element combine, that's chemical change. A physical change would be the leaves falling off the trees. A chemical change would be if there is a fire and all the trees burn.	4
Mixture	17. If you add Nestle's Quick to milk and stir until no more will dissolve, (A) what kind of solution has been formed? Saturated (B) predict what you would need to do to make more mix dissolve. Heat the milk and stir more.	4
Mixture	18. In class, we viewed several samples of mixtures like sand and iron filings, fruit salad, and buttons. Give another example of a mixture and explain how you would separate it. Separated by filtering, evaporation or settling	4

PART 4 - ESSAY

Concept	Questions/Answers	Pts.
Compounds	19. In our world over 6,000,000 chemical compounds exist and scientists need to classify them as organic and inorganic compounds. In a paragraph, explain the difference between the two and give examples.	8

Organic compounds have carbon and most were once alive. Inorganic compounds do not contain carbon. An example of an organic compound is methane. An example of inorganic is lemon juice.

The differences between organic and inorganic compounds have carbon in its substance. Inorganic has four compounds that go under inorganic, organic only has two compounds that go under compound. Inorganic has oxides, acids, bases, and salts; the organic has hydrocarbon and other.

20. Place a check below the number to rate how well you think you did.

1	2	3	4	5
very poor	not good	good	pretty well	excellent