High school chemistry students' learning of the elements, structure, and periodicity of the periodic table: contributions of inquiry-based activities and exemplary graphics

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HIGH SCHOOL CHEMISTRY STUDENTS’ LEARNING OF THE ELEMENTS, STRUCTURE, AND PERIODICITY OF THE PERIODIC TABLE: CONTRIBUTIONS OF INQUIRY-BASED ACTIVITIES AND EXEMPLARY GRAPHICS

A Dissertation
Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

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B.S., Louisiana State University, 1985
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ABSTRACT

The main research question of this study was: How do selected high school chemistry students' understandings of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics? The research question was answered using a multiple case study/mixed model design which employed elements of both qualitative and quantitative methodologies during data collection and analyses.

The unit study was conducted over a six-week period with 11th-grade high school students enrolled in a chemistry class. A purposive sample of six students from the class was selected to participate in interviews and concept map coconstruction (Wandersee & Abrams, 1993) periodically across the study. The progress of the selected students of the case study was compared to the progress of the class as a whole. The students of the case study were also compared to a group of high school chemistry students at a comparative school.

The results show that the students from both schools left traditional instruction on the periodic table (lecture and textbook activities) with a very limited understanding of the topic. It also revealed that the inquiry-based, visual approach of the unit study helped students make significant conceptual progress in their understanding of the periodic table. The pictorial periodic table (which features photographs of the elements), used in conjunction with the graphic technique of data mapping, enhanced students understanding of the patterns of the physical properties of the elements on the periodic table. The graphic technique of compound mapping helped students learn reactivity patterns between types and groups of elements on the periodic table. The recreation of the periodic table with element cards created from the pictorial periodic table helped students progress in their understanding of periodicity and its key concepts. The
Periodic Table Literacy Rubric (PTLR) proved to be a valuable tool for assessing students’ conceptual progress, and helped to identify a critical juncture in the learning of periodicity. In addition, the PTLR rubric’s historical-conceptual design demonstrates how the history of science can be used to inform today’s science teaching.
INTRODUCTION

Rationale

Professor James H. Wandersee (personal communication, April 25, 1996), in the course of conveying my master’s exam question, referred to the periodic table as the “premier graphic tool of chemistry.” Many historians of science agree. Strathern (2000) states, “With the periodic table chemistry came of age.... chemistry now had a central idea upon which an entire new range of science could be built” (p. 292). Goh and Chia (1989) also describe the importance of the periodic table, “The periodicity of elements... ranks as one of the greatest generalizations in science” (p. 747). Hill and Lederman (2001) write that the periodic table is the “starting point for chemistry” (p. 33). Both the National Science Education Standards (National Research Council [NRC], 1996) and the Benchmarks for Scientific Literacy (American Association for the Advancement of Science [AAAS], 1993) affirm the importance of this “premier graphic tool of chemistry” and its related concepts in middle and high school science instruction.

Although the periodic table is a foundational topic in chemistry, educators have found that it is difficult to teach the periodic table and its related concepts for understanding. As stated by Goh and Chia (1989), “Periodicity has also been identified as a difficult concept for beginning chemistry students to understand” (p. 747). Volkmann (1996) writes:

The periodic table is one of the most fundamental organizing systems of chemistry. However, for most high school students, the periodic table may as well be written in hieroglyphics. I have tried most of the traditional strategies for teaching the periodic table--memorizing symbols and oxidation numbers,
experimenting with familial and periodic properties, and memorizing periodic law--to little avail. My students attack these tasks with vigor but rarely develop the underlying organizing schema--that the chemical and physical properties of the elements occur in repeating patterns when arranged in ascending order by atomic number. (p. 37)

Goh and Chia (1989), Goth (1986), and Volkman (1996) offer the following reasons students have difficulty learning periodicity:

1. Periodicity is an abstract concept (Goh & Chia, 1989; Volkman, 1996).
2. Periodic patterns are complex (Goh & Chia, 1989; Goth, 1986; Volkman, 1996).
3. Students do not have sufficient prior knowledge of the elements and their properties (Goh & Chia, 1989).
4. Students do not have sufficient prior experience identifying periodic patterns (Goh & Chia, 1989).
5. The data (illustrating periodicity) presented in table form or line graphs can be visually overwhelming (Goth, 1986).
6. Students have difficultly relating periodic patterns presented in line graphs to the structure of the periodic table (Goth, 1986).

Given the importance of the periodic table, and the difficulty students have in understanding the concepts, it is surprising that very limited research has been done on students’ conceptions of periodicity and how they develop conceptual understanding. Since the advent of cognitive science, numerous studies have been conducted to discover students’ ideas about particular science concepts. According to Sadler (1998), the focus of these studies cover quite a range of important science concepts from “astronomy to
zoology” (p. 267). The studies undertaken in the field of chemistry also represent a variety of topics and include the following: chemical symbol, formula, equation (Al-Kunied, 1993), the particulate nature of matter (Griffiths & Preston, 1992), chemical change (Hesse & Anderson, 1992) stereochemistry (Lyon, 1999), and hydrogen bonding (Henderleiter, Smart, Anderson & Elian, 2001).

During a search to locate information related to teaching periodicity only three research studies were found. These studies by Abraham, Grzybowski, Renner, and Marek (1992), Bonar (1999), and Lehman, Koran, and Koran (1984) revealed little insight into students’ conceptions of the periodic table and the concept of periodicity. While numerous articles have been published suggesting techniques and methods to teach the elements and/or periodicity, none formally addressed their effectiveness in improving student learning. Therefore, student learning of the elements and the periodic table is virtually unexplored territory for science education. There was a need for a study employing methods that were sensitive enough to assess how students’ develop an understanding of this important topic.

Mintzes and Wandersee (1998b) outline “five promising areas of future research in science education,” which include: (a) critical junctures in learning, (b) comparative knowledge structures of experts and novices, (c) knowing and feeling, (d) metacognition and, (e) intervention strategies.

This research study directly addressed these three areas in the context of learning about the elements, structure, and periodicity of the periodic table. The study investigated the conceptual changes that took place as students learned about the periodic table. It examined the value and effectiveness of the Periodic Table Literacy Rubric (PTLR, (see
Appendix A), an instrument developed by the researcher that attempts to delineate stages that students move through as they progress from the novice to the expert level (area #2) of understanding of the periodic table. A pilot study (Appendix B) revealed that one of the stages identified on the rubric could be a possible critical juncture (area #1), and this study attempted to test this initial finding. This study also assessed the effectiveness of a unit study consisting of four research-based intervention strategies (area #5) that were designed to help students move from the novice level to the expert level of understanding of the periodic table. These four strategies or activities were piloted in the spring of 2001 (Appendix B). All three participating students showed qualitative gains in their conceptual understanding of the elements and the periodic table. Each student had also progressed at least one level on the PTLR during his/her participation in the unit study.

**Research Questions**

The main research question of this study was: How do selected high school chemistry students' understandings of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics?

Additional subquestions were:

1. What do these students learn, incrementally, via each of these inquiry-based, primarily visual instructional activities?

2. Is the categorization and tracking of these students' conceptual progress using the researcher-designed, history-of-chemistry-based, standards-linked, Periodic Table Literacy Rubric [PTLR] helpful to the chemistry teacher and/or these students in monitoring understanding?
3. Are there critical junctures in the learning of periodicity, and if so, which, if any, of the visual learning activities seem to help students pass such research-identified, "learning checkpoints" successfully?

Research Vee Diagram

A research Vee diagram (Gowin, 1981) was constructed to graphically illustrate and summarize this research program. The main research question is located at the top of the Vee, and the subquestions are located inside the Vee. The left side of the Vee identifies the theoretical and conceptual basis of this research. At the bottom of the Vee the major events of the research are listed. The right side of the Vee describes the methods that were used, along with the knowledge and value claims of the study.

Flow Chart of Research

The Flow Chart of Research was constructed to report the major events of this research study, including the historical development of the study, the sequence of the activities of the unit study, and data collection that occurred before, during, and after the activities of the unit study.

Definition of Terms

Compound data map - a graphic technique in which the elements forming a compound are mapped out on a blank periodic table, connecting lines are drawn between the elements forming each compound, and a linking line is labeled with the compound name, chemical formula, and the representative element groups that combined to form the compound.

Concept map - a graphic representation of the structure of knowledge in which concepts are linked together in a hierarchy to form propositions.
Figure 1. Research Vee Diagram.

THEORIES
Meaningful Learning Theory
Expert-Novice Theory
Tutte's Theory of Graphic Design
Solsio's Theory of Visual Cognition
Atomic Theory of Matter

RESEARCH QUESTIONS
How do selected high school chemistry students' understanding of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics?

SUBQUESTIONS
1. What do these students learn incrementally, via each of these inquiry-based, primarily visual instructional activities?
2. Is the categorization and tracking of these students' conceptual progress using the researcher-designed, history-of-chemistry-based, standards-linked, Periodic Table Literacy Rubric (PTLR) helpful to the chemistry teacher and/or these students in monitoring understanding?
3. Are there critical junctures in the learning of periodicity, and if so, which, if any, of the visual learning activities seem to help students pass such research-identified "learning checkpoints" successfully?

PRINCIPLES
Meaningful learning involves the activation of prior knowledge, and the connection of new concepts to related concepts in prior knowledge.
Experts see meaningful patterns.
Graphic excellence is attained by the use of simple, but powerful graphic designs.
When the elements are listed in order of increasing atomic number, repeating sequences (periods) of elements appear revealing groups of elements with similar physical and chemical properties.

CONCEPTS
Element, compound, atomic structure, chemical symbol, chemical family, chemical series, physical property, chemical property, periodic table, periodicity, data map, compound data map, multifunctioning graphic element, small multiple, expert, novice, scientific literacy, chunking, rubric, history of science.

EVENTS
Interviews
Concept map coconstruction
Field note-taking
Element surveying
Achievement testing
Instructional activities

TRANSFORMATIONS
Transcription & analysis of audiotapes of student interviews
Transcription & analysis of videotapes of activities/Interviews
Analysis of concept maps
Descriptive statistical analysis of element surveys
Descriptive & inferential statistical analysis of achievement tests
Analysis of student activity sheets

RECORDS
Audiotapes of student interviews
Videotapes of selected activities/Interviews
Coconstructed concept maps
Fieldnotes
Element surveys
Achievement tests
Student activity sheets

VALUE CLAIMS
The pictorial periodic table, data mapping, compound mapping and periodic table reconstruction are valuable instructional tools for teaching the periodic table. The PTLR is a valuable tool for assessing student learning of the periodic table.

KNOWLEDGE CLAIMS
A visual, inquiry-based instructional approach to the periodic table may lead to significant conceptual development. A traditional instructional approach to the periodic table may lead to limited conceptual development. There is a critical juncture in the learning of periodicity.
Figure 2. Flow Chart of Research.
Conceptual change - the restructuring of knowledge that occurs during meaningful learning.

Critical juncture - a point in the process of conceptual change, at which the learner is unable to restructure knowledge and acquire a superordinate concept.

Data map - a map or graphic on which additional variable(s) or theme(s) are represented that go beyond the basic map or graphic design.

Human constructivism - an epistemology which proposes that there is an external and knowable world, and that humans actively construct their knowledge of this world.

Meaningful learning - the activation of prior knowledge related to any new information, and the association of the new knowledge to relevant prior knowledge.

Multifunctioning graphical element (MGE) - a graphic component that communicates information in several different ways.

Periodicity - when the elements are listed in order of atomic number, repeating sequences of elements (periods) appear revealing groups of elements with similar physical and chemical properties.

Periodic Table Literacy Rubric (PTLR) - a rubric designed to measure students’ conceptual progress in learning about the elements, structure and periodicity of the periodic table.

Small multiple - a small graphic unit that is designed to be repeated within a data display, as the basic design remains constant, the viewer can visually focus on changes in the data.

Subsumption - the incorporation of new concepts into our existing conceptual
knowledge structures.

Superordinate learning - the acquisition of a new general or superordinate concept, which requires significant knowledge restructuring.

Vee diagram - a diagram that visually represents the questions, events, methods, and theoretical and conceptual foundation of a research study.
LITERATURE REVIEW

Scientific Literacy

The National Science Education Standards (NRC, 1996), the Benchmarks for Scientific Literacy (AAAS, 1993), and Science for All Americans (Rutherford & Ahlgren, 1990) all emphasize the necessity of scientific literacy for all American students. Science for All Americans identifies seven different facets of scientific literacy, among which the following two are the most relevant to the proposed research:

Understand some of the key concepts and principles of science [and be]... able
to use scientific knowledge and ways of thinking for personal and social purposes. (Rutherford & Ahlgren, 1990, p. x)

Both the National Science Education Standards and the Benchmarks for Scientific Literacy identify the elements, structure, and periodicity of the periodic table as “key concepts and principles of science” that students should understand and be “able to use... for personal and social purposes.” What follows are the relevant benchmarks from these two documents, listed in order of their recommended introduction at the middle and high school levels. These benchmarks indicate the minimum levels of science literacy that students should achieve by the end of middle school, and by the end of high school.

Elements - Grades 5-8

There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances that we encounter. (NRC, 1996, p. 154)

Scientific ideas about elements were borrowed from some Greek philosophers of 2,000 years earlier, who believed that everything was made from four basic
substances: air, earth, fire, and water. It was the combinations of these “elements” in different proportions that gave other substances their observable properties. The Greeks were wrong about those four, but now over 100 different elements have been identified, some rare and some plentiful, out of which everything is made. Because most elements tend to combine with others, few elements are found in their pure form. (AAAS, 1993, p. 78)

Groups or families of elements - Grades 5-8

There are groups of elements that have similar properties, including highly reactive metals, less-reactive metals, highly reactive non-metals (such as chlorine, fluorine, and oxygen), and some almost completely nonreactive gases (such as helium and neon). An especially important kind of reaction between substances involves combinations of oxygen with something else--as in burning or rusting. Some elements don’t fit into any of the categories; among them are carbon and hydrogen, essential elements of living matter. (AAAS, 1993, pp. 78-79)

Structure of the periodic table and periodicity - Grades 9-12

When elements are listed in order according to the number of protons (called atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This ‘Periodic Table’ is a consequence of the repeating pattern of outermost electrons and their permitted energies. (NRC, 1996, pp. 178-179)

When elements are listed in order by the masses of their atoms, the same sequence of properties appears over and over again in the list. (AAAS, 1993, p. 80)
The National Science Education Standards (NRC, 1996), the Benchmarks for Scientific Literacy (AAAS, 1993), and Science for All Americans (Rutherford & Ahlgren, 1990) also all emphasize the importance of teaching the history of science. Although these documents do not specifically discuss the historical event of Mendeleyev’s invention of the periodic table, it was an important component in this research study.

**Historical Development of the Periodic Table of the Elements**

**Pre-Mendeleyevian Understanding and Classification of the Elements**

Robert Boyle is attributed with theoretically defining the concept of *element* as we know of it today. Strathern (2000) reports, however, that in 1661 Boyle “didn’t actually know what one was” (p. 179). Antoine Lavoisier, in his 1789 work, *Elementary Treatise on Chemistry*, refined Boyle’s definition of an element and included a listing of 33 elements (Strathern, 2000). Of these 33 elements identified by Lavoisier, eight were actually compounds and two were forms of energy (Strathern, 2000). Idhe (1964) remarks that,

> Although his list of 33 elements included a few forms of energy and a few compounds in addition to a few postulated elements, he directed chemical thought toward a group of well-known substances that were significant as elements. His errors were not sufficiently serious to handicap chemists and his correct hunches provided a foundation on which others could build. (p. 231)

Shortly thereafter, John Dalton also produced a list of elements in his book *New System of Chemical Philosophy* in 1808 (Strathern, 2000). He included a table of 20 elements, which employed a symbol and an atomic weight for each element (Robin, 1992).

Kauffman (1969) and Strathern (2000) identify Dobereiner of Germany, De Chancourtois of France, and Newlands of England, as the most prominent of the many who discovered patterns
among the elements prior to Mendeleyev. Johann Wolfgang Dobereiner is thought to be the first to classify the elements into groups having similar properties (Ihde, 1964; Kauffman, 1969; Strathern, 2000). In 1829 he identified groups of elements, each having three elements with similar properties, in which there was a systematic progression of atomic weight values (Ihde, 1964; Strathern, 2000). Dobereiner called this pattern the “Law of Triads,” and it initially applied to 9 of the 54 known elements (Strathern, 2000).

Mierzecki (1991) reports that Alexandre-Emile Beguyer de Chancourtois is noted as “the first ‘classifier’ who succeeded in relating the arrangement of the elements according to their increasing atomic masses to the existence of the families of elements with similar properties” (p. 140). In 1862, Chancourtois plotted the elements in order of atomic weight on a cylinder, and discovered a repeating pattern of properties occurring every 16 elements (Ihde, 1964). Chancourtois called his helical graph the “Telluric Screw” (Strathern, 2000).

In 1864, John Newlands also listed the elements in order of atomic weight, and discovered his “Law of Octaves,” which identified a repeating pattern of properties at every eighth element (Strathern, 2000). Muir (1907) quotes Newlands: “The eighth element, starting from a given one, is a kind of repetition of the first, like the eighth note of an octave in music” (p. 359). Ihde (1964) states that Newland’s discovery was not well received by his colleagues in the Chemical Society. On the occasion of Newland’s presentation, Ihde reports, “One Carey Foster, who holds no other claim to fame, rose to ask facetiously if Newlands had ever sought to classify the elements in alphabetical order” (pp. 242-243).

Mendeleyev’s Development of the Periodic Table of the Elements

While there were many attempts to design a comprehensive classification system for the elements prior to 1869, Demetri Mendeleyev is often credited with the discovery of the periodic
table and its underlying concept of periodicity (Bouma, 1989; Kauffman, 1969). Historians report that he developed it while writing his book, Principles of Chemistry in 1869 (Graham, 1983; Leicester, 1961; Partington, 1964; Strathern, 2000). Below is listed what was known about the elements and their classification at the time Mendeleyev developed his table (Strathern, 2000).

1. Each element consisted of a particular type of atom.

2. The atoms of the same element had the same properties, and the same atomic weight.

3. Some of the elements could be classified together into groups of elements having similar properties.

4. The elements could be listed in increasing order of atomic weight.

Why did it take so long for someone to discover the underlying pattern of periodicity? The answer to the periodic puzzle was not immediately obvious to Mendeleyev, or his predecessors and contemporaries, because they did not have all the pieces of the puzzle. Only 63 of the 92 naturally occurring elements were known at the time of Mendeleyev’s discovery, and some of those had incorrect atomic weight values, placing them out of proper order in an atomic weight line-up (Graham, 1983; Strathern, 2000).

What enabled Mendeleyev to finally see the pattern? Strathern (2000) writes that Mendeleyev had an encyclopedic knowledge of the elements and their properties; he was a renowned expert. Strathern also reports that Mendeleyev often played “Patience,” a card game similar to Solitaire, which proved to be a very valuable analogy, which he used to help him see the pattern. Ihde (1964) and Strathern (2000) both state that Mendeleyev was aware of the frequent inaccuracies of the atomic weight values of his day. Knowing the uncertainty of these
values gave him confidence to deviate from a strict ordering of the elements by then-current atomic weight, and to later defend the atomic weight inversions in his periodic table.

As stated previously, Mendeleyev discovered the pattern of periodicity while writing a textbook on chemistry. He was confronted with the problem of having no logical system to organize or classify the natural elements (Leicester, 1961; Partington, 1964; Strathern, 2000). Mendeleyev felt that the key to developing a classification system was finding a link between the ordering of the elements by atomic weight and the grouping of elements with similar properties (Strathern, 2000). To help him visualize the problem, he created a set of element cards (Graham, 1983; Ihde, 1964; Leicester, 1961; Strathern, 2000). Each element card displayed the element’s symbol, atomic weight, and characteristic chemical and physical properties (Graham, 1983). Mendeleyev then organized the element cards in a manner similar to the way he organized playing cards when playing the card game “Patience” (Graham, 1983; Strathern, 2000). Strathern gives details of actual moments of Mendeleyev’s discovery in his book *Mendeleyev’s Dream*. He reports that while Mendeleyev was studying this graphic arrangement of cards, he fell asleep. He quotes Mendeleyev’s reflection on the moment of his discovery after waking from his nap: “I saw in a dream a table where all the elements fell into place as required. Awakening, I immediately wrote it down on a piece of paper” (Strathern, 2000, p. 286).

**Forms of the Periodic Table and Other Graphics That Represent Periodicity**

Since Mendeleyev first published his periodic table in 1869, numerous modifications have been made to the traditional rectangular table format in an effort to better communicate information about the elements and the concept of periodicity (Bouma, 1989; Fernelius & Powell, 1982). Some of these alternative forms of the table have been proposed to help students make meaningful connections to the elements that comprise the table. Bouma (1989) states:
Every teacher has been faced with the pupils’ question: ‘Could you please explain what it’s all for?’ And indeed, what use is there in a wall poster with all the elements neatly lined up without any reference to daily life? (p. 743)

In his article Bouma describes a version of the table that has the traditional format, symbols, and numbers, but prominently displayed in each element block is a colorful graphic depicting some use for the element. Below the graphic are listed four different uses for the element. In reference to this table Bouma writes, “A periodic table like this confronts pupils day by day with the social relevance of chemistry. They cannot but observe how our science plays a predominant role in everyday life, a fact we want to emphasize in education.”

Two different versions of the table have been created to represent relative element abundance. There are those of Carrado (1993), who varies the size of the element blocks to proportionally represent element abundance on the earth, and Dutch (1999), who represents solar, lunar, and earth element abundances using small circles on a gridless periodic table.

Some of the alternative forms of the rectangular table have been proposed to better facilitate student understanding of the concept of periodicity. For example, the chemical education community has offered a number of suggestions as to what data should be represented on the periodic table (Campbell, 1989; Laing, 1989; Saturnelli, 1985). Traditionally, the table has displayed the element symbol, atomic number, and atomic weight in each element block. Campbell (1989), in reference to this format states:

Most chemistry classrooms display a wall chart labeled, ‘Periodic Table of the Elements.’ What does a student see? Well, there is a set of rectangular boxes arranged in rows and columns, each box containing some alphabetical symbols and numerals that are difficult (even impossible) to read. Nor is [sic] any of the
symbols periodic. Not even the format is truly periodic.... Perhaps this interprets why such an aperiodic table is not readily used and understood by students.... Let us make the periodic table of the elements live up to its name.

(p. 740-741)

Campbell (1989) goes on to suggest that the periodic table used by students of chemistry be revised by removing the atomic weight values and adding information that clearly demonstrates periodicity. He presents a modified form of the table that includes the following information: ionic charge, radioactivity, atomic size, and ionic size. Atomic and ionic size are represented by both numerical values and, graphically, by small circles.

Similarly, Lehman (1982) had previously constructed two modified forms of the table (expanded and visual) for use in his research study. Lehman’s expanded version included the number of outer shell electrons, notation of outermost sublevel, atomic size values, along with atomic number and mass values. The graphic version differed from the expanded version by the addition of semicircles representing atomic size.

Some chemistry educators (Goth, 1986; Osorio, 1990) caution that although these expanded versions are handy for the expert, they may be overwhelming for those first learning about the periodic table. Goth (1986) states that,

It is often difficult for beginning students to grasp the full utility of the concept of periodicity. First, the amount of data is vast and it is usually presented in table form or in traditional two-dimensional line graphs. In both cases, the periodic behavior may be lost in the details of the data. How is a beginning student to see the ‘forest’ of periodicity among the ‘trees’ of 103 electron configurations arranged in a table? (p. 836)
Osorio (1990) also provides a similar warning, “The periodic tables in current use have been overloaded with physical and chemical data that, though of high practical value, in attempting to provide the maximum usefulness have unwittingly masked the didactic character that the table inherently possesses” (p. 563).

In addition to the traditional rectangular format of the periodic table, many alternative graphic representations of periodicity have been proposed, representing quite a variety of two- and three-dimensional geometric shapes (Fernelius & Powell, 1982). Two-dimensional forms include the following: circular (Bouma, 1989), spiral (Tufte, 1990), pyramidal (Fernelius & Powell, 1982), and trapezoidal (Osorio & Goldschmidt, 1989) Three-dimensional forms include the periodic tree (Scerri, 1997) and the “Periodic Building of the Elements” (He & Li, 1997, p. 792).

**Instructional Strategies to Familiarize Students With the Elements of the Periodic Table**

Numerous articles have been published describing instructional activities that have been used to increase students’ knowledge of the elements. These activities can emphasize one or more of the following aspects of element knowledge: interdisciplinary connections (e.g., language arts, history, art, etc.), everyday or real-life relevance (e.g., occurrences, uses), or the physical and chemical properties of the elements. Those that are of an interdisciplinary nature include the following: element riddles (Wieder, 2001), element puns (Vorndam, 1999), and element-related postage stamp collecting (Garrigos, Ferrando, & Miralles, 1987). On the artistic end of the spectrum, Dreyfuss (2000) had his students paint the element blocks on his car creating what he calls the “Periodicar,” a rolling periodic table.

One of the most common activities to enhance student knowledge of the elements is the “element report” project, in which each student is assigned an element to research. Rajan (1983)
### Table 1: Summary of Articles Related to Forms of the Periodic Table and Other Graphics That Represent Periodicity

| Periodic tables that emphasize connections to the elements. | Bouma (1989) – Element blocks include graphics depicting uses of the elements.  
Dutch (1999) – Small circles used to represent solar, lunar, and earth element abundances. |
| Proposed additions to the table to make it more periodic. | Campbell (1989) – Add numerical and graphic information to represent ionic charge, radioactivity, atomic size, and ionic size.  
Lehman (1982) – Add numerical and graphic information to represent outer shell electrons, notation of outermost sublevel, and atomic size. |
| Warnings about adding information to the table. | Goth (1986) – “Periodic behavior may be lost in the details of the data” (p. 836).  
Osorio (1990) – Current periodic tables mask the didactic character of the table. |
Tufte (1990) – 2-D spiral graphic.  
He & Li (1997) – 3-D “Periodic Building of the Elements” (p. 792). |

provides an outline of the major research areas, which include element history, atomic data, occurrence, properties, and uses. Variations of this basic format may include writing poetry (Abisdris & Casuga, 2001), creating slogans (Lustick, 1997), compiling a database (Corcoran & Allen, 1994), conducting “Chemistry Court” (Corcoran & Allen, 1994), constructing a classroom size periodic table (St. John & Stevens, 1989), identifying current research (Schneider, 1992), and
creating an element yearbook (Spain, 1992). As evidenced before, the “element report” can emphasize all three areas of element knowledge.

Rajan (1983) defines “descriptive chemistry” as “…that portion of the chemistry curriculum devoted to a few industrial processes or the preparation, manufacture, properties, and uses of elements and compounds” (p. 217). Both Rajan (1983) and Woodgate (1995) emphasize the importance and value of incorporating descriptive chemistry into introductory chemistry courses. The “element report” discussed above is one means of accomplishing this, however, each student gains an in-depth knowledge of only one element. Woodgate (1995) states,

It is possible to teach descriptive chemistry to students who are reluctant to learn chemistry. The key is active teaching of the subject, using as a template the periodic table, that powerful tool that features far too little in most first-year courses. (p. 622)

This concept of “active teaching” of the elements would seem to be exemplified in Marshall’s (2000) “Living Periodic Table” and Cherif, Adams, and Cannon’s (1997) “Plain Periodic Table Learning Activities.” Marshall’s “Living Periodic Table” is a collection of 87 samples of the elements in their elemental state. Also included in the collection is a sample of the mineral from which each element was originally discovered, along with an item that shows a commercial application for each element. Solomon and Bates (1991) also describe a similar collection, one that is limited to element samples. Both Marshall (2000) and Solomon and Bates (1991) describe how the element samples can be used to demonstrate the physical, chemical, and nuclear (radioactive) properties of the elements. Deavor and Deavor (1995) apply this same idea of “active teaching” of the elements at the elementary level. They describe the development of “chemistry learning centers,” which feature:
...household compounds by exhibiting empty boxes or bottles of Epsom salt, table salt, shampoo, baking soda, and hydrogen peroxide along with sheets of copper, zinc, and aluminum foil. Students also were introduced to the periodic table by displaying colorful copies of the periodic table.... (p. 798)

Cherif, Adams, and Cannon’s (1997) “Plain Periodic Table Learning Activities” exemplifies Woodgate’s (1995) “active teaching” of the elements by “using as a template the periodic table.” In their activities students use a grid-only version of the periodic table to document their research findings of the various properties, uses, and occurrences of the elements. For example, students identify the elements that are essential for human life, and write the elements in their respective grid spaces on the periodic table.

**Instructional Strategies to Assist Students in Learning About the Structure and Periodicity of the Periodic Table**

Frequently mentioned in the literature are activities to teach periodicity involving the organization of objects into the form of the periodic table or some type of classification system analogous to it. Bolmgren (1995), Goh and Chia (1989), and Tejada and Palacios (1995) all describe activities in which students develop a classification system using a set of objects where each object illustrates one or more properties of a particular element. In the activity described by Bolmgren, each element is represented by a small cardboard circle. The circles vary in size proportionally with their atomic weight, and elements of the same group have the same color, representing similar chemical behavior. Students are instructed to arrange the circles in increasing order of size (atomic mass), and to identify any patterns that they see. When students notice the repeating pattern of colors of the circles, they are told to arrange the repeating rows on top of one another so that all the circles of the same color form a column.
Table 2: Summary of Articles Related to Instructional Activities That Familiarize Students With the Elements

<table>
<thead>
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<tr>
<td></td>
<td>Garrigos et. al. (1987) – Postage stamp collecting.</td>
</tr>
<tr>
<td></td>
<td>Lustick (1997) - Emphasis on creating slogans.</td>
</tr>
<tr>
<td></td>
<td>Corcoran &amp; Allen (1994) – Emphasis on compiling a database and conducting “Chemistry Court.”</td>
</tr>
<tr>
<td></td>
<td>Solomon &amp; Bates (1991) – Collection limited to element samples.</td>
</tr>
<tr>
<td>Element mapping.</td>
<td>Cherif et. al. (1997) – “Plain Periodic Table Learning Activities,” identification of properties, uses, and occurrences of elements.</td>
</tr>
</tbody>
</table>

Goh and Chia (1989) use three different sets of cards in a learning cycle format to teach periodicity. The exploration phase includes two activities. In the first, students use a set of cards representing the days of a month to recreate a calendar month. In the second, they are given a set of element cards that have different-sized circles proportionally representing atomic size, and different numbers of tabs representing the number of valence electrons. Students are instructed to
organize the element cards in a way similar to that of the calendar cards. In the concept development phase, the calendar analogy is used to help students understand the concept of periodicity. Students develop a classification system in the final application phase using a set of element cards, which have diagrams with concentric circles representing electron configuration.

Tejada and Palacios (1995) developed “Chemical Elements Bingo,” which uses element cards that illustrate the number of valence electrons of each element. Additional information about physical and chemical properties is also included on the back of the cards.

Irons (1989) conducted an activity similar to the three above, however instead of using objects or cards, students used actual element samples to develop a classification system of the elements. After students first tested the element samples for metallic character, reactivity with water and reactivity with acid, they were instructed to organize the elements into a classification system based on the physical and chemical properties that they observed.

Daniel (1997) and Volkmann (1996) both describe classification activities using objects that do not explicitly represent the properties of individual elements. Volkmann has students classify various sizes of nuts and bolts into an organizational scheme, and then relate this scheme to the organization of the periodic table. Daniel suggests a number of different objects that can be used including: rubber stoppers, playing cards; and he also suggests bodily-kinesthetic modeling, where students of varying stature use their bodies to represent atomic size. Daniel also has students find analogous periodic patterns in non-chemistry contexts such as music, fashion, sports, and so forth.

Several authors use line graphs of periodic properties to facilitate the learning of periodic trends. Daniel (1997) has students create and analyze atomic number versus atomic radius (and also ionization energy) graphs using graphing calculators. Summerlin and Borgford (1989) have
students illustrate the periodic trends of ionization energy and electronegativity by creating 3-D bar graphs on a periodic table model comprised of soda straws and microscale trays. Volkman (1996) has students construct line graphs using data from the nuts-and-bolts classification activity discussed above, as well as graphs of periodic properties.

**Table 3: Summary of Articles Related to Instructional Activities That Assist Students in Learning About the Structure and Periodicity of the Periodic Table.**

| Classification activities with element cards. | Bolmgren (1995) – Cards are small cardboard circles representing atomic weight and, colored to represent varying chemical behavior. |
| Classification activities with actual element samples. | Irons (1989) – Classification after chemical tests are performed. |
Daniel (1997) and Levine (1990) both challenge students with projects that require them to use their creativity and apply what they have learned about periodicity. Both authors propose having students create new forms of the periodic table. After introducing students to alternative forms of the periodic table (cubic, pyramidal, spiral, etc), Levine requires students to create unique organizational designs for the elements and write a revised periodic law to describe that design. Daniel suggests having students create 3-D forms of the table. Daniel also uses the interdisciplinary approach by having students create poems, plays, songs, or stories that describe periodic patterns.

**Research on Student Learning of Periodicity**

Three research studies related to the periodic table have been identified (Abraham et al., 1992; Bonar, 1999; Lehman et al., 1984). Abraham et al. (1992) studied eighth-grade students’ understanding of periodicity. They used short-answer questions to determine students’ understanding of periodicity and to identify any alternative conceptions students had related to periodicity. In the section of the test dealing with periodicity, students were presented a mock periodic table containing fictitious elements and their corresponding atomic weights. Students were provided several chemical formulas of compounds involving different elements and asked to infer chemical formulas of other combinations of elements. This question was designed to test their understanding of relationships within and among the families of the periodic table. Only 2 of the 247 students demonstrated an understanding of this concept. The second question asked students to predict the atomic weight of the one element listed on the table, which had no accompanying atomic weight. This question was designed to test their understanding of the periodic trend related to atomic weight. Thirty-seven percent of the students demonstrated an understanding to this question. However, their responses to the open-ended follow-up question
led researchers to question whether many of those answering correctly understood the concept. Their research findings indicated that there were very few student misconceptions related to periodicity. Students either understood the concept, or they did not; and most did not.

In the second study, Lehman et al. (1984) explored how various structural modifications of the periodic table influenced student learning. They used three different periodic tables in their study. The basic version of the three tables had the element symbol, atomic number, and atomic weight in each element block. The expanded version was modified to include electron configuration, atomic size, and outer shell electrons in each element block. The graphic version differed from the expanded version by the addition of semicircles in each element block, which represented atomic size. All students were given a posttest that measured their ability to use one of the three periodic tables to acquire information and solve qualitative problems.

The researchers found that students who were not familiar with the periodic table tended to use the graphic periodic table more effectively. They also reported that among students who were familiar with the periodic table, low ability students tended to use the basic version more effectively, and higher ability students tended to use the graphic version more effectively. However, the internal validity of these findings was challenged by the very limited length and the nature of the treatment session. The experimental treatment was completed in one day during one 50-minute class period, and consisted of students reading over a set of materials and answering questions using one of the versions of the periodic table discussed above. One of their final conclusion is well-supported by the results of their study. They recommended that “additional research is needed with subjects of different abilities using modified tables to study different content for longer periods of time...” (p. 893).
The quantitative research methods that were employed in these two studies were not designed to detect subtle changes in students’ understanding of the periodic table. Therefore, it is not surprising that neither study revealed how students learn about the periodic table over time. While Abraham et al. (1992) did use some open-ended test items in an attempt to identify misconceptions, none was detected.

Bonar’s (1999) study of high school chemistry students’ understanding of the periodic table proved to be slightly more productive. He probed students’ understanding using analogical activities, short constructed-response items, and interviews as they proceeded through a unit study on the periodic table. In the first phase of the study students were asked to develop a classification system for books in a library using rules based on the organizational structure of the periodic table. Bonar reports that no student was able to produce a layout that followed all the given rules. The second phase of the study involved students responding to two constructed response questions, and the results are discussed below. The third phase of the study consisted of a clinical interview where students were asked to solve problems using a fictitious periodic table. This table and accompanying problems were essentially the same as those used by Abraham, et al. (1992). Bonar reported that students “did not show any use of the fact that elements in the same column share chemical properties or the idea of a periodic trend in atomic weight. Instead, the students’ explanations centered on the questions as logic puzzles” (p. 10).

The students’ inability to solve the novel problems presented in the first and last phase of the study can be understood in light of the results of the second phase. Bonar (1999) reported that the following three student conceptions emerged from this phase:

1. The periodic table is organized by electron configuration.
2. An element’s position on the table determines its properties.
3. The periodic table presents a lot of information. These responses indicate that the students had a limited understanding of the structure and periodicity of the periodic table, and therefore would understandably have difficulty solving a problem in a new context. Bonar concludes by stating that there is a need for more extensive study of student conceptions of the periodic table.

**Tufte’s Theory of Graphical Excellence**

Tufte (1983, 1990) has developed a theory of graphic excellence, which can be used to guide the selection and design of graphics. The first and most basic principle of this theory is to use simple, but powerful graphic designs that efficiently and effectively illustrate complex concepts or relationships. Tufte identifies a number of graphic designs that exemplify this principle. Among these are the small multiple, the multifunctioning graphical element (MGE), and the data map. A small multiple is a small graphic unit that is designed to be repeated within a larger graphic display, such as a thermometer scaled to report high and low temperatures placed at each city on a map. The basic design unit remains constant, so that the viewer can visually focus on changes in temperature data. The multifunctioning graphical element (MGE) is a graphic component that communicates information in several different ways. A data map (or thematic map) is a map or graphic on which additional variable(s) or theme(s) are represented that go beyond the basic geographic map or graphic design (such as a weather map). In this study, each of these designs played an important role in communicating to students the structure of the periodic table and the complex concept (or construct) of periodicity.

**The Pictorial Periodic Table**

The periodic table, in almost all of its forms, is a collection of small multiples, with each individual element block being a small multiple design unit. On a pictorial periodic table (Menzel,
individual element photographs are the small multiples featured within each element block. In addition to being small multiples, the element photographs also serve as multifunctioning graphical elements (MGE). In this role as MGEs, each element photograph communicates the following information:

1. element color;
2. element phase;
3. metallic or nonmetallic character of element;
4. use of the element (iron as a nail, helium in a balloon); and
5. reactivity of element (alkali metals are either submerged in oil or enclosed in glass).

This form of the table seems to have great power in communicating the structure and periodicity of the periodic table, and also embodies the familiar phrase: “a picture is worth a thousand words.”

The pictorial form of the periodic table exemplifies not only the first principle of Tufte’s theory, but also a second component which he calls the principle of escaping flatland. Escaping flatland involves finding creative ways of vividly representing the four dimensions of our world on graphics that are bound by the two dimensions of the printed page. The pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), which features actual photographs of the elements, should help students visually escape the flatland of the periodic table. The pictorial form also helps them escape the grid-based abstract land of the traditional form of the periodic table on which the elements are normally presented.

**Periodic Table Data Maps**

The periodic table is frequently used as a data map to present information about the elements (atomic number, electron configuration, boiling point, etc.). In this study a generic
version of the periodic table (each element block contained only the element symbol and atomic number) served as the basic form of a data map, on which a number of different variables or themes were mapped out by students.

**Visual Cognition**

Solso (1994) presents a theory of visual cognition which describes how we come to “see” graphics such as the periodic table. According to this theory, our vision ranges 180 degrees horizontally and 130 degrees vertically. However, our sharpest vision, where we can actually focus and make very fine distinctions, occurs in a zone of only about 1-2 degrees in the center of our range of vision. Due to this limited focus zone, we cannot instantaneously “see” all the details of the periodic table. Instead, we scan the graphic and stop frequently to focus on interesting parts. As we do this we cognitively construct an image in our “mind’s eye” of the graphic from the many snapshots we take during the focusing stops. Both Solso (1994) and Tufte (1983, 1990) report that our eyes easily fatigue during this image construction process. Therefore, graphics like the pictorial periodic table, which facilitate this scanning and the image construction process, are a powerful tool to help students learn the patterns embedded in the periodic table.

**Cognitive Science**

Bruer (1993) defines cognitive science as the science of the mind, “how we think, remember, and learn” (p. 2). He reports that the field of cognitive science began at an information science conference in 1956. Cognitive science pioneers Noam Chomsky (language development) and George Miller (short-term memory) led the charge that behaviorism, the reigning psychological theory at the time, was not adequate to explain the phenomena they were observing in their research. As a theory, behaviorism held that because mental processing is not directly observable, it was outside the realm of scientific research. Anything occurring inside the “black
box” of the mind was off-limits for scientific investigation. Miller, Chomsky, and other conference participants agreed that the human mind processed information in terms of symbols, and that the science of psychology had to include the study of unobservable mental symbol structures and operations. This was the beginning of cognitive science, a science of the mind, psychological theorizing which attempts to discover what goes on inside the “black box.”

**Short-Term Memory**

At this conference, George Miller (as cited in Bruer, 1993) presented his study of short-term memory capacity. His research indicated that short-term memory is able to hold 7 plus or minus 2 symbols or chunks of information at a time. These symbols or chunks are not limited to single digits or letters. If the individual data units can be formed into meaningful chunks or groups, the total number of individual data units that can be remembered is greatly increased. Miller proposed that when we learn, we actively process information as we look for ways to group bits of information into meaningful patterns called “chunks.” Miller called this process “chunking.” Much of the learning related to the periodic table involves helping students “chunk” individual elements into any number of meaningful periodic patterns (e.g., groups or families, periods or series, sublevel blocks, or groupings based on metals/nonmetals and phase). For the instructional activities of this study, exemplary graphics were either chosen and/or designed to help facilitate this “chunking” process.

**Expert-Novice Research**

Since that conference, some of the most significant cognitive science research has focused on the comparison of experts and novices in various fields (Mintzes & Wandersee, 1998a). This “expert-novice” research has the goal of discovering precisely what makes an expert an expert, and what are the most efficient and effective means to help novices become experts in a given
area. Mintzes and Wandersee (1998a) report that this research has revealed that experts have the following characteristics:

1. Experts tend to excel singularly in their domain of knowledge and that transfer to other domains is quite limited in most instances;
2. Experts tend to see large meaningful patterns in their knowledge domain, and this enables them to solve problems more quickly;
3. Experts generally possess a strongly hierarchical cohesive framework of related concepts...; and
4. Experts typically have strong ‘metacognitive’ or self-monitoring skills. (p. 43)

Bruer (1993), similarly, identifies three main factors upon which expertise in a given area depends:

1. Highly organized domain-specific knowledge.
2. Domain-specific metacognitive skills.
3. General learning strategies or skills (e.g., using models or analogies).

Simon and Chase (as cited in Haberlandt, 1999; Bruer, 1993) conducted expert-novice research in the area of chess by studying the differences between expert and novice chess players. Some had theorized that chess experts are experts because they plan ahead several moves. Their research revealed, however, that both expert and novice chess players plan ahead several moves. The difference was in how they viewed the game board. Experts had visually chunked or grouped individual pieces into familiar patterns, so that when they looked at the board they saw patterns, not individual pieces. Novices, on the other hand, did not see patterns, but rather only saw individual chess pieces.
The research of Simon and Chase (as cited in Haberlandt, 1999; Bruer, 1993) provides clues as to how students who are “periodic table novices” might initially view the periodic table. There appear to be a number of similarities between the processes of developing expertise in playing chess and in using the periodic table. Periodic table novices, like chess novices, might only see the surface features of the periodic table. In the mind’s eye of novices in both areas, they may initially see a grid pattern, with objects on the grid boxes that have virtually no meaning. For the chess novice it is unusual wooden or plastic pieces, for the periodic table novice it is rather meaningless numbers and letters. The instructional task at hand is to help periodic table novices move to and go beyond an understanding of the numbers and letters on the periodic table, to “see” and remember the patterns represented on the periodic table, which, according to the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy (AAAS, 1993), is the hallmark of periodic table expertise.

**Mendeleyev the Expert**

Strathern (2000), in his book *Mendeleyev’s Dream*, provides a glimpse back into history to the event of Mendeleyev’s discovery of the periodic table. When viewed through the lenses of cognitive science, this glimpse provides a historical example of periodic table expertise, and insight into how we can help students who are periodic table novices become periodic table experts. Strathern (2000) writes that, at the time of his discovery, Mendeleyev had an encyclopedic knowledge of the elements. He evidently had the characteristic of expertise that Bruer’s (1993) refers to as “highly organized domain-specific knowledge” or what Mintzes and Wandersee (1998a) identify as a “strongly hierarchical cohesive framework of related concepts” (p. 43). Mendeleyev was also very familiar with the groups or “chunks” of elements with similar chemical and physical properties. Mintzes and Wandersee refer to this aspect of expertise as,
“Experts tend to see large meaningful patterns in their knowledge domain, and this enables them to solve problems more quickly” (p. 43). Mendeleyev was fond of the card game “patience” (solitaire), and he used this game as an analogy to help him discover the repeating patterns of periodicity. The use of analogies is a general learning strategy or skill that Bruer (1993) identifies as a mark of expertise.

**Human Constructivism**

Human constructivism is an epistemology or theory of knowledge that was developed by Joseph Novak (1998a). It is a theoretical synthesis of constructivist epistemology and David Ausubel’s assimilation theory of meaningful learning (Mintzes & Wandersee, 1998a). At the heart of this theory is the belief that humans actively construct their knowledge of the world around them. We think in terms of concepts, and our knowledge consists of concepts that are linked or connected together to form propositions. The concept of meaning is derived from the links or connections between the concepts that make up our knowledge. We construct meaning for a new concept when we link that concept to other concepts in our prior knowledge. This process is called meaningful learning, and it is the foundational educational principle of this research study.

Novak (1998b) found in his research that, “learners who developed well-organized knowledge structures were meaningful learners, and those who were learning primarily by rote were not developing these structures and/or their knowledge included many misconceptions” (pp. 10-11). This study was designed to help students develop “well-organized knowledge structures” related to the periodic table, which is one of the components of periodic table expertise.

**Ausubel’s Assimilation Theory of Meaningful Learning**

Cognitive psychologist David Ausubel first presented his theory of meaningful learning in the early 1960’s. At the heart of his theory is the distinction between meaningful learning and rote
learning (Mintzes & Wandersee, 1998a; Novak & Gowin, 1984). The following quote of Ausubel summarizes his basic principle of meaningful learning, “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly (Ausubel 1968 [2nd ed., 1978])” (Novak & Gowin, 1984, p. 40). Resnick (1989) also refers to this principle as “Knowledge thus begets knowledge” (p. 2). Ausubel identifies subsumption and superordinate learning as the two main types of meaningful learning. Much of the learning related to the periodic table is subsumption, in which students learn additional details about familiar concepts (element, metal, group, etc.). However, there are some major concepts that students will be presented with (i.e., periodicity), with which they have had almost no experience. During the process of learning these “major concepts,” they become new general concepts in the cognitive framework, under which many other more specific existing concepts (i.e., groups, atomic number, etc.) will be organized. This is the process of superordination or superordinate learning.

**Conceptual Change**

Mintzes and Wandersee (1998b) discuss the work of Thomas Kuhn and Stephen Toulmin, both philosophers of science, who developed theories of how scientific knowledge changes over time (the nature of conceptual change). Kuhn stressed the view that conceptual change is a process of “radical restructuring” of scientific knowledge, such as when one scientific theory replaces another. Toulmin promoted a view that conceptual change was an “evolutionary restructuring” of knowledge, where scientific knowledge changes gradually over time. As mentioned above, Novak’s (1998a) human constructivism is a synthesis of Ausubel’s psychology of learning and the constructivist epistemology of knowledge restructuring. Novak’s synthesis proposes that meaningful learning is the mechanism of the knowledge restructuring that occurs
during conceptual change (Mintzes, Wandersee & Novak, 1998). He also proposes that students learn science by the same knowledge restructuring processes as scientists when they develop new scientific knowledge. Integral to the human constructivist view are the parallels between the processes of conceptual change and meaningful learning. Toulmin’s gradual or weak form of knowledge restructuring occurs during the meaningful learning process of subsumption, and involves the assimilation of new concepts into existing knowledge structures (i.e., metals are mainly solids), requiring a minimal reordering of concepts. Kuhn’s strong or radical restructuring occurs during the acquisition of a superordinate concept (i.e., the understanding of periodicity), and requires a significant reordering of cognitive structures. These are the “ah ha” or “Now I see!” moments that occur in both the scientists’ lab and the science classroom (Mintzes, Wandersee & Novak, 1998).

**Critical Junctures**

Mintzes and Wandersee (1998b) posit that, “Longitudinal studies have found that students typically traverse particularly critical periods in the learning of selected scientific concepts such as evolution, the particulate nature of matter, and the structure and function of cells, among others (Novak & Musonda, 1991; Pearsall, Skipper, & Mintzes, 1997; Trowbridge & Wandersee, 1994)” (p. 84). When students arrive at these “critical periods” or “critical junctures,” it is often during superordinate learning when strong or radical knowledge restructuring is taking place (Mintzes & Wandersee, 1998b; Trowbridge & Wandersee, 1998). The concept of periodicity is a superordinate science concept similar to those listed above. Both Volkman (1996) and Goh and Chia (1989) describe periodicity as a difficult concept for students to understand. This researcher’s pilot study revealed a possible critical juncture at the point of acquiring the superordinate concept of periodicity. Therefore, one of the research subquestions selected for this
study was to discover if the new data support a “critical juncture” in the learning of the concept of periodicity.

**Research Methodology**

Over the past three decades, there has been much debate within the field of education in general over the issue of qualitative versus quantitative research methods (Howe & Eisenhart, 1990; Patton, 1990; Tashakkori & Teddlie, 1998). Both of these basic methodology types were the progeny of distinctly different research paradigms or worldviews. Quantitative methods were derived from the positivist research paradigm, and qualitative methods were derived from the naturalist/constructivist paradigm (Patton, 1990). The debate often centered around the question of which is the superior research paradigm: positivism or constructivism. According to several researchers in the pragmatist camp, however, the historical debate has been unnecessary. Patton (1990) argues that methods can be separated from the paradigm out of which they originated, therefore, a researcher need not have to adopt and defend a particular paradigm in order to use its respective methodology. Tashakkori and Teddlie (1998), Patton (1990), and Howe and Eisenhart (1990) all agree that the real question should be, “Which methodology best fits the research question being posed?” Tashakkori and Teddlie (1998) refer to this as the dictatorship of the research question.

**Complementary Nature of Qualitative and Quantitative Methods**

Wandersee and Demastes (1992) report that science education is not exempt from this debate about research methodology, and point out that many fail to understand that some questions are better answered by qualitative methods and some questions by quantitative methods. Gall, Borg, and Gall (1996) discuss the complementary roles that qualitative and quantitative methods exemplify. They state that qualitative methods have a unique value in the initial
exploration of a phenomenon, to discover the how, what, and why of phenomena using in-depth studies of a small number of participants. Quantitative methods, on the other hand, can play a confirmatory role, as they attempt to replicate the findings of qualitative studies, but with larger numbers of participants. Wandersee and Demastes (1992) use the analogy of binocular vision to illustrate the complementary nature of these two methodologies. Each method may yield a different view of the topic of interest, however when combined, the composite view offers a clearer picture of the phenomenon of interest. They state that whether the methods are used separately in different studies, or together in a mixed-methods study, qualitative and quantitative methods complement each other.

**Mixed Methodology**

Tashakkori and Teddlie (1998) go one step further with the complementary idea, and recommend the use of mixed methodology to answer almost any research question in the social sciences, regardless of whether that question is exploratory or confirmatory. They state:

> We encourage researchers to use appropriate methods from both approaches to answer their research question. For most applications in the social and behavioral sciences, these research questions are best answered with mixed methods or mixed model research designs rather than a sole reliance on either the quantitative or the qualitative approach. (p. x)

This study employed a mixed methods design as both qualitative and quantitative data collection methods were used.

**Mixed Model Designs**

Tashakkori and Teddlie (1998) define “mixed model” studies as mixed methods studies that “combine the qualitative and quantitative approaches within different phases of the research
process” (p. 19). Patton (1990) refers to the practice of combining different elements of these two methodologies as “methodological mixes.” This study utilized a “mixed model” design to answer the research question, as the two methodologies were combined during the analysis of the data. The qualitative data (e.g., interviews, concept maps) underwent both a qualitative analysis, and a quantitative analysis (quantification using the PTLR). Similarly, the quantitative data (survey and test) underwent both a quantitative analysis (statistical) and a qualitative analysis (content).

**Inference Quality**

Tashakkori and Teddlie (1998) in their book *Mixed Methodology*, propose a new term that can be used universally to describe the quality of the conclusions of both qualitative and quantitative research. They offer the phrase “quality of inferences” as an alternative to the term “internal validity” (quantitative research), and the terms “trustworthiness” or “credibility” (qualitative research). They also discuss the “MAXMINCON” design principle, as a means to enhance the “inference quality” of a study. The “MAX” means that the research design should MAXimize the experimental variance of a study. In this multiple case study, the purposive sample included students representing the maximum range of student ability levels (high, medium, low) to achieve this goal of maximum experimental variance. Also, the study was conducted over 19 class periods, which allowed sufficient time for the students to develop an understanding of the elements, structure, and periodicity of the periodic table, in contrast to all of the previous studies cited. The “MIN” refers to MINimizing the error variance. One means to accomplish this is to use reliable data gathering instruments. This researcher possesses well-developed interviewing and concept map coconstruction skills, thereby rendering him a reliable data collection instrument. The “CON” refers to the CONtrol of extraneous variables. During the pilot study, the four instructional activities (each of which lasted several days) were conducted over a period of three
months. In this study, the four activities occurred sequentially in a continuous unit study. This was done in an effort to help minimize the effect of extraneous variables that could influence student learning.

**Triangulation**

Gall, Borg, and Gall (1996), Patton (1990), and Tashakkori and Teddlie (1998) discuss the principle of triangulation as a means of strengthening the “inference quality” (credibility or validity) of a study. Two types of triangulation were applied in this study. “Methodological triangulation” (Patton, 1990; Tashakkori & Teddlie, 1998) is the use of multiple methods, and it was applied in this study as both qualitative and quantitative methods were used. “Data triangulation,” (Patton, 1990; Tashakkori & Teddlie, 1998) the use of several sources of data, was also employed, using several types of both qualitative and quantitative data. Both types of triangulation allowed the researcher to view the phenomena of interest from different perspectives, and thereby enhance the quality of the inferences resulting from this study.

**Qualitative Data Collection Methods**

With regard to research methodology, Wandersee, Mintzes, and Novak (1994) write, “Studies designed to measure the conceptual change resulting from an intervention need to employ assessment techniques sensitive to subtle changes in students’ understanding” (p. 202). Mintzes and Wandersee (1998b) report, “We have come to rely heavily on three remarkably powerful tools for exploring students’ understandings of scientific concepts and documenting changes in those understandings (p. 66). In both of these references, the researchers identify the structured interview and concept mapping as two of the three “powerful tools” or “assessment techniques,” that are sensitive enough to measure conceptual change. This study was designed to identify the “changes in students’ understanding” as they learned about the periodic table during
an “intervention.” This was the rationale for the selection of these two techniques as the primary sources of data for this study.

**Concept Mapping**

Concept mapping was developed by Joseph Novak and his research group at Cornell University, and is based on Ausubel’s assimilation theory of learning (Novak, 1990). Edmondson (2000) defines concept mapping as a “tool for representing the interrelationships between concepts in an integrated, hierarchical manner” (p. 20). Trowbridge and Wandersee (1998) describe concept mapping “as a device to illustrate the hierarchical, conceptual, and propositional nature of knowledge” (p. 115). Wandersee (1990) uses the metaphor of the map to illustrate the great value of concept maps in exploring cognitive structure and documenting learning. When early explorers created maps of the territory they were discovering, their maps documented what they had learned about the geographic features of the new area. Thus, as Wandersee states, “To map is to know.” Therefore when students construct concept maps during the learning process, the maps provide insight into the new conceptual territory they have traversed, and the state of their “knowing.”

Edmondson (2000) reports that the “use of concept maps as evidence of progressive change over time is perhaps one of the most promising applications of concepts maps in assessing student learning (p. 23). Novak (1990) also reports that concept maps “can be a highly sensitive tool for measuring changes in knowledge structure” (p. 946). Along these lines, Trowbridge and Wandersee (1998) promote the use of concept maps to document conceptual change and identify critical junctures and misconceptions (alternative conceptions).
Concept Map Coconstruction

Concept map coconstruction (Wandersee & Abrams, 1993) is a process in which the researcher acts as a guide and assists students in the construction of a concept map representative of their knowledge. Three variations of the technique have been employed in separate studies by Abrams (1994), Trowbridge (1995), and Griffard (1999). Abrams (1994) provided students with the superordinate concept, and then listed concepts students had given during an interview that immediately preceded the coconstruction session. The researcher then guided the students in the construction of their concept maps, using only the concepts and propositions that the students supplied. Trowbridge (1995) used the same coconstruction format, except that he provided the superordinate term, and then asked students to generate the remaining terms for their map. Griffard (1999) provided students with a list of concepts that they categorized as either familiar or unfamiliar, and then coconstructed a map with the concepts with which students were familiar. In this study, the researcher utilized aspects of all three of the above in the coconstruction process. The researcher provided students with the superordinate concept (periodic table) and several key “seed” concepts, and then reminded students of the concepts they had supplied during the interview before asking them for any additional terms they wanted to add.

Structured Interview

Cognitive studies in the late 1970’s began to focus on how students learned particular science concepts, often using in-depth interviews in the place of conventional multiple-choice tests (AAAS, 1993). Sadler (1998) reports that the qualitative interview has “proven incredibly productive” (p. 265) in the discovery of student misconceptions, and has “revealed most of what we know about students’ ideas in science” (p. 267).
Interviews can be classified based on their format, which can vary from unstructured to highly structured or standardized (Novak & Gowin, 1984; Tashakkori & Teddlie, 1998). The structured or clinical interview was developed by Piaget to study the cognitive development of children in the early part of the twentieth century (Novak & Gowin, 1984). During the structured clinical interview, the researcher asks carefully designed questions to probe students’ understanding of a topic (Novak & Gowin, 1984; Sutherland, Smith, & Cummings, 2000). Special objects, photographs, and so forth often serve as a meaningful focus of the questions. Novak and Gowin (1984) report that, "The clinical interview, when well executed, provides by far the most penetrating assessment of student’s knowledge" (p. 128). The structured interview served as the primary data source on how students learned about the periodic table. The interview questions and objects designed for this study were tested during the pilot study, and were subsequently revised.

Reliability and Validity of Qualitative Data Collection

For both interviewing and concept map coconstruction, the researcher is the data collection instrument. Patton (1990) states that the “researcher as the instrument” is the greatest strength and weakness of qualitative methods. The reliability and validity of the data is dependent upon the skill of the researcher. For example, a skilled researcher is prepared to rephrase questions in order to provide clarification for students. Reducing students’ misunderstanding and confusion increases the reliability of the data. A skilled researcher is also prepared to ask additional questions that probe deeper into a student’s understanding, when a student reveals interesting information such as a misconception or error. In this case the validity of the data is strengthened by providing a broader and deeper view of the phenomena of interest. This
researcher has honed his skills conducting interviews and concept map coconstruction sessions during three different research studies, the pilot study being the most recent.
METHODS

Research Design

This research study was an exploratory investigation of how students learned about the elements, structure, and periodicity of the periodic table as they participated in four carefully designed instructional activities that together formed a unit study on this topic. The research question was best answered using a multiple case study/mixed model design (Tashakkori & Teddlie, 1998) which employed elements of both qualitative and quantitative methodologies during data collection and analyses. The units of analyses were the individual students who participated in the study, and the four instructional activities. The study had two confirmatory components. First, the progress of the selected students of the case study was compared to the progress of the class as a whole. Secondly, the students of the case study were compared to a group of students at a comparative school. The “Flow Chart of Research” (see page 8) and Gowin’s Vee diagram (see page 6) detail the different phases of the research project.

Research Sites

Pine High School, the primary research site, is a small, rural, grades 9-12 public school located in the Deep South. The enrollment at this school is approximately 400 students, 94% African-American and 6% white. The total percentage of students classified as receiving free or reduced lunch is 81%. The school district in which the research site is located received additional funding from the Rural School and Community Trust and the Delta Rural Systemic Initiative (an agency of the National Science Foundation that serves Arkansas, Louisiana, and Mississippi) within the last five years. The research site is typical of the 551 rural, high minority enrollment (63%), high poverty schools (69% of students receiving free or reduced lunches) that the Delta Rural Systemic Initiative serves.
The primary research site was a sample of convenience, as it was one of the two assigned high schools of this researcher, who serves this school system as a science instruction facilitator. This relationship enhanced the administration and the data collection of the study. The researcher had developed a rapport with the students, teachers and administrators in the school over the last 14 years.

East High School, the comparison school, mirrors the demographics of Pine. The enrollment at this school is approximately 350 students, 93% African-American and 7% white. The total percentage of students classified as receiving free or reduced lunch is 79%. The school district in which East High School is located is also affiliated with the Delta Rural Systemic Initiative, and is a typical school served by that organization. East High school is within an hour’s drive of the primary research site.

**Research Participants**

At Pine High School, the study was conducted with 11th-grade high school students enrolled in a chemistry class. The teacher of the selected chemistry class was a first-year teacher with a bachelor’s degree in biochemistry. The researcher, a veteran public high school chemistry teacher, taught the class throughout the unit study, with occasional assistance from the teacher. The chemistry class was part of each student’s seven-period schedule of classes, with each class period lasting approximately 50 minutes. Prior to the research, the teacher had covered the structure of the table (groups, periods, metals/nonmetals, sublevel blocks) and periodic law over 11 class periods. The primary instructional methods were lecture and the completion of worksheets using the textbook. Students’ principal use of the periodic table in chemistry was to do electron configuration problems. They reported that their only exposure (prior to chemistry) to
the periodic table was in biology, where they used it to find atomic number and mass. Most had not learned the element symbols prior to chemistry.

A purposive sample (Tashakkori & Teddlie, 1998) of six students from this class at Pine High School was selected to participate in interviews and concept map coconstruction (Wandersee & Abrams, 1993). The student sample represented a cross-section of the class, and included males and females at a range of achievement levels. The selection criteria included previous grades earned in chemistry class, teacher recommendation and willingness to be interviewed. The six students in the sample are referred to as S1, S2, S3, S4, S5, and S6. In this sequence the students are rank-ordered according to the chemistry grade they had at the beginning of the study (i.e., S1 had the highest average and S6 had the lowest average).

At East High School, the comparison phase of the study was conducted with six high school students (five 11th-graders, one 12th-grader) enrolled in a chemistry class. The teacher of this chemistry class had 17 years of experience and an educational specialist degree. The chemistry class was part of a block schedule of classes, with each class period lasting approximately 90 minutes. Prior to the research study, the teacher had covered the structure of the table (groups, periods, metal/nonmetal, phases) and periodic law in one class period. The lesson began with a lecture using the textbook and ended with students learning about the physical and chemical properties through a hands-on activity with actual element samples. Students’ use of the periodic table in chemistry was to name compounds, write chemical formulas, calculate molecular weight, and balance equations. Most of the students in the sample had very limited exposure to the periodic table before taking chemistry, although all reported learning the element symbols in a prior high school science class.
A purposive sample of six students from this class at East High school was identified, based on identical selection criteria as those in Pine High, to participate in interviews and concept map coconstruction. This student sample also represented a cross-section of the class, and included males and females at a range of achievement levels. The six students in the sample are referred to as CS1, CS2, CS3, CS4, CS5, and CS6, following the same rank-ordering sequence as used for Pine High.

**Data Collection**

The study used a variety of data collection methods to provide a comprehensive approach for detecting and documenting changes in students’ conceptual understanding across the activities of the unit study. The pilot study had employed these same methods, and they proved to be very productive in assessing students’ understanding. The procedure for data collection is outlined in the Flow Chart of Research (see page 9).

**Interviews**

The students at Pine High School were interviewed before the unit study and after each of the four activities, with the interview after Activity Four serving as the final interview for the study. The interview schedule is illustrated on the Flow Chart of Research (see page 9). Protocols were developed for each interview, and are included in Appendix C. The students at East High School were interviewed with the same protocol used for the first interview at Pine High School. Each interview was audiotaped and transcribed. The teachers at both high schools were interviewed about the instruction that they had provided on the periodic table.

**Concept Map Coconstruction**

The concept map coconstruction immediately followed the student interviews. The researcher provided several seed concepts for each student to use, and probed him/her for
concepts he/she supplied during the interviews. Each concept map was coconstructed using a computer notebook and Inspiration (2000), a graphics construction program designed for concept mapping. All of the coconstructed concepts maps are included in Appendix D.

Field Notes and Student Activity Sheets

After each class period, the researcher reviewed the day’s activity, and recorded field notes consisting of observations made during the lessons. Student activity sheets were collected at the end of each class session, and returned for completion at the following class if necessary. A portfolio of each student’s worksheets was maintained throughout the study. Samples of student work from each activity are included in Appendix E.

Pre- and Posttest

A posttest (Appendix F) developed by Lehman (1982) for his doctoral study was administered to all of the students in the Pine High School chemistry class as a pre- and posttest. Permission to use this test was obtained from the author (Appendix G). An item analysis of the test is included in Appendix H. Lehman (1982) reported that the reliabilities calculated using the Kuder-Richardson’s KR-21 formula were .51 for the multiple choice items, .52 for the constructed answer items, and .72 for the total test. The content validity of this test for the proposed study was determined by reviews conducted by members of this researcher’s doctoral committee.

Element Survey

The element survey (Appendix I) was administered as a pre- and postsurvey to all of the students in the class. It was developed by the researcher, and the general form of it was tested in the interviews during the pilot study. The survey was also reviewed by members of the researcher’s doctoral committee.
Protection of Human Subjects

An application for exemption for Institutional Review Board (IRB) oversight was submitted and was subsequently approved. The approved application is included in Appendix J. Also included in Appendix J are the abstract of the study, the letter for parents and students explaining the study, consent/assent agreement and the researcher’s Human Participant Protection Education for Research Teams Completion Certificate from the National Institute of Health, all of which were submitted with the application for exemption. Also submitted were the interview protocols in Appendix C. Prior to the beginning of the research project, letters were sent home to the parent(s) or guardian(s) of students in the study. Assent was obtained from the students who participated in the study, and consent from their parent(s) or legal guardian(s).

Data Analysis

The Analysis of Data graphic in Appendix K illustrates the procedure used to analyze the data. All of the data, both qualitative (interview transcripts, concept maps, field notes, student worksheets) and quantitative (achievement test scores and survey results), underwent a qualitative content analysis (Tashakkori & Teddlie, 1998). Patton (1990) states that the challenge of qualitative analysis is “to make sense of massive amounts of data, reduce the volume of information, identify significant patterns, and construct a framework for communicating the essence of what the data reveal” (pp. 371-372). The identification of “significant patterns” in the data from this study was facilitated, in part, by employing a “simple valence analysis” procedure described by Tashakkori and Teddlie (1998). In this procedure, a relatively small number of coding schemes or categories are developed a priori by the researcher to aid the search for patterns in the data. During the pilot study, the researcher identified several such categories, and these were used to code the data obtained in this study. The units of analyses in the qualitative analysis...
were the individual students in the purposive sample and the four activities of the unit study. The data from each activity (student worksheets, field notes) and subsequent interview (audiotaped and/or videotaped transcripts, labeled periodic tables, concept maps) were summarized into several tables, which are included in Appendix L. Table 4 presents an overview of these summary tables.

**Table 4: Overview of Tables Presented in the Results’ Section Organized by PTLR Level**

<table>
<thead>
<tr>
<th></th>
<th>PTLR Level 1 Elements</th>
<th>PTLR Level 2 Properties</th>
<th>PTLR Level 3 Group or Family</th>
<th>PTLR Level 4 Organization of Periodic Table</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interview One (Pre)</td>
<td>Table 1</td>
<td>Table 2</td>
<td>Table 3</td>
<td>Table 4</td>
<td></td>
</tr>
<tr>
<td>Interview Two</td>
<td></td>
<td>Table 5</td>
<td>Table 6</td>
<td>Table 7</td>
<td></td>
</tr>
<tr>
<td>Interview Three</td>
<td>Table 8</td>
<td>Table 10</td>
<td>Table 11</td>
<td>Table 12</td>
<td></td>
</tr>
<tr>
<td>Interview Four</td>
<td>Table 13</td>
<td>Table 14</td>
<td>Table 15</td>
<td>Table 16</td>
<td></td>
</tr>
<tr>
<td>Activity Four</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Table 17</td>
</tr>
<tr>
<td>Interview Five (Post)</td>
<td></td>
<td></td>
<td>Table 21</td>
<td>Table 22</td>
<td>Table 19</td>
</tr>
<tr>
<td>East High Interview</td>
<td>Table 24</td>
<td>Table 25</td>
<td>Table 26</td>
<td>Table 27</td>
<td>Table 20</td>
</tr>
</tbody>
</table>

All of the data underwent a quantitative analysis (Tashakkori & Teddlie, 1998). The PTLR (found in Appendix A) was used to quantify each student’s understanding of periodicity. At each assessment stage of this research project (see page 9) the above data were analyzed, and a PTLR literacy level was assigned to each student in the sample group.

The quantitative data (achievement test scores and survey results) also underwent quantitative analyses using descriptive and inferential statistics. Student responses to the element survey were reported in terms of the percentage of elements with which students were familiar. These percentages were calculated for the sample and the class. Student responses to the achievement test were reported in terms of the percentage correct for the complete test, and by
subcategory on the test. A “paired ‘t’ test” (Sprinthall, 1997) was performed to determine if there was a statistically significant difference between the achievement pre- and posttest scores for all the class members participating in the study.

**Limitations**

This research was an exploratory study with limited generalizability due to the small number of students in the sample group and its purposive nature. The sample and the comparative sample of students were taught by different teachers for different lengths of time (adding additional variables), even though school compositions were similar. The class, sample, and comparative sample included only African-American students, which also limits generalizability, and eliminates the possibility of cross-ethnic comparisons. It should be noted, however, that Census 2000 found that 33% of the population of the state in which the research was conducted is African-American, ranking it 5th among the 50 states.

**The Periodic Table Unit Study**

The periodic table unit study was comprised of four different activities (Appendix M). It was conducted with the chemistry class at Pine High School during 19 class periods, which occurred during the six-week research study. The breakdown by activity is as follows: Activity One, four class periods; Activity Two, five class periods; Activity Three, four class periods; Activity Four, five class periods. A brief description of each is given below.

Activity One: The Pictorial Periodic Table was designed to give students a meaningful introduction to the elements and the periodic table. Students began the activity by observing and recording the physical properties of a number of common, but unknown element samples. They used their observations to identify these elements. In the next phase, students used the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987) as a reference to create data maps of the
colors and phases of the elements. Through this activity they were introduced to the periodic patterns related to the physical and chemical properties of the elements (color, metal versus nonmetal, phase, reactivity) and the organization of the elements into groups or families.

Activity Two: Product Analysis I was designed to help students identify real-life occurrences and applications of the elements as they learned about the location, organization, and chemical reactivity of the elements. In this activity students identified and recorded the elements and compounds contained in various cereal and multimineral supplement products. They used this information and the Periodic Table of the Elements for Biology (Orr, 1997) to create data maps illustrating the biological relevance (e.g., nutrient, toxin) of each identified element. In the next phase, students created compound data maps using the compounds identified in the products. Through this process students identified reactivity patterns among the elements on the periodic table (metals combine with nonmetals to form ionic compounds, nonmetals combine with nonmetals to form covalent compounds).

Activity Three: Product Analysis II had a design and format very similar to that of Activity Two, and extended and reinforced the concepts learned previously, as students found the elements in everyday household products. Student groups were given eight sets of products, with each product set representing elements from a particular group or family. Students analyzed the compounds in each product of a group or family set and identified which of the elements from the group were contained in that product. Students recorded the elements and certain compounds in each product, and as before, created a compound data map for certain identified compounds. Students not only learned about the reactivity patterns among element groups, but the reactivity characteristics of individual element groups within the periodic table.
Activity Four: Recreating the Periodic Table, Mendeleyevian Style was designed to facilitate student understanding of the concept of periodicity, the organizational structure and the periodic trends of the periodic table. Students were first given sets of element cards created from the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987) with each card featuring the photograph of a particular element. Students were then guided step-by-step, in the reconstruction of the periodic table. During the reconstruction process, the calendar analogy was used to introduce and discuss the concept of periodicity. Also at this point, the similar physical and chemical properties of the elements within each group or family were reviewed. Once the table was reconstructed, the connection between electron configuration and the organizational structure of the periodic table was discussed. To illustrate the periodic trend of reactivity within groups, students were shown a short video segment (Chemistry at work: Image database for chemistry, 1991) which featured reactions of the alkali metals with air and water. Students then used periodic tables with small circles representing atomic size to identify that respective periodic trend.

Development of the Periodic Table Unit Study

Good, Herron, Lawson, and Renner (as cited in DeBoer, 1991) define science education as “the discipline devoted to discovering, developing, and evaluating improved methods and materials to teach science’’ (p.188). One of the purposes of this research study was to evaluate the effectiveness of the periodic table unit study that has been developed, piloted, and revised over the last five years by the researcher. The “discovery” and “development” of the graphics, objects, and activities of this unit study were guided by the following:

1. meaningful learning theory (Human Constructivism),
2. expert-novice research (cognitive science),
3. Tufte’s theory of graphical design,
4. Solso’s theory of visual cognition, and

5. a standards-based understanding of chemistry.

The Periodic Table Research Study concept map (Appendix N) identifies the theoretical basis of the development of this unit study. The Periodic Table concept map (Appendix O) was developed by the researcher using the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy (AAAS, 1993). It was reviewed by members of the researcher’s doctoral committee. This concept map illustrates the standards-based conceptual understanding of the periodic table that guided the development of the unit study. Also incorporated in the unit study are many of the suggested graphics, objects, and activities that were uncovered by the researcher during library work and identified in the previous literature review section. This unit study addressed the reasons students have difficulty learning periodicity, which were suggested and discussed in the introductory section. The following discussion of the development of this unit study is organized using those reasons.

Reasons #1: Periodicity Is an Abstract Concept

The first reason why students have difficulty learning periodicity, as listed in the introduction, is that periodicity is an abstract concept (Goh & Chia, 1989; Volkman, 1996). In an effort to reduce the level of abstraction of this topic, all four activities of the unit study used an inquiry-based or discovery approach, and were designed to provide meaningful learning experiences for students. These activities followed a “guided discovery” format, which DeBoer (1991) defines as “a form of discovery teaching in which the teacher takes an active part in organizing instructional activities so that students can be led to make “discoveries” (p. 210).

Goh and Chia (1989) state, “Periodicity is an abstract concept. Many secondary school students need concrete learning aids to illustrate abstract concepts” (p. 747). Each of the four
activities utilized “concrete learning aids” in an effort to make learning of the periodic table more meaningful. For example, Activity One featured the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), which was chosen to introduce the elements and the periodic table because it is one of the most meaningful or “concrete” forms of the table that exists. Activity Two and Three both utilized actual household products that students were familiar with, in an effort to help students make real-life connections to the elements of the periodic table. Activity Four, like Activity One, used the pictorial periodic table to help students understand the concept of periodicity.

**Reason #3: Students Are Not Familiar With the Elements**

A third reason students have difficulty learning periodicity is that they do not have sufficient prior knowledge of the elements and their properties (Goh & Chia, 1989). Goh and Chia (1989) state, “Consideration of the properties of a minimum of 20 elements is essential to real comprehension of the concept. Most students’ knowledge of the elements concerned is not sufficient to identify patterns” (Goh & Chia, 1989, p. 747). Findings from the pilot study provide support for this statement. The two students who had a substantial knowledge of the elements at the beginning of the study ended with a well-developed understanding of the periodic table, and the student who knew very little about the elements made very limited progress in her understanding of the periodic table.

This emphasis on prior and prerequisite knowledge of the elements for learning periodicity seems to concur with the findings of expert-novice research and with the history of science. It would appear that students need to have a meaningful understanding of the elements, their relevance, location on the table, and their properties, before they can “chunk” them into meaningful periodic patterns. Strathern (2000) reports that Mendeleyev, at the time of his
discovery of the periodic table, had an encyclopedic or expert-level knowledge of the elements, and of their physical and chemical properties. He was very familiar with the groups or “chunks” of elements having similar chemical and physical properties.

DeBoer (1991) in his book, A History of Ideas in Science Education: Implications for Practice, outlines a composite model of science teaching that includes the following as a component:

Science study must involve as much direct contact with the physical world as possible. If the students have not had previous experience with the objects or phenomena that are essential for understanding the concept being taught, then the teacher should provide those experiences for students. (p. 238)

As stated above, the pilot study revealed that some students had very little knowledge of, and experience with, the elements. Therefore, the focus of the development of this unit study (the first three activities in particular) was to provide students with “direct contact” with the elements.

In Activity One of the unit study, students came in “direct contact” with the elements in their pure state, physically as actual samples, and visually, both as photographs on the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987) and as they are featured in reactions on a videotape. The use of actual element samples in instruction is described by Deavor and Deavor (1995), Marshall (2000), and Solomon and Bates (1991). Marshall refers to his collection of element samples as a “Living Periodic Table.” The collection that was used with this study was most similar to that of Deavor and Deavor (1995), who used a small number of elements that are relatively safe to handle (e.g., aluminum, iron). Since some of the elements are hazardous to store and handle, the simulated “direct contact” with them was visual through the pictorial table and video.
In Activity Two and Three students came in “direct contact” with elements that were found in household products that they see or use everyday. This was similar to Deavor and Deavor’s (1995) use of household products in their “chemistry learning centers.” The students in the pilot study identified these two activities as their favorites of the four, reporting that they learned about the relevance, diversity, and frequency of the elements in the products. The household products were chosen according to the following criteria:

1. Popular products students use, or with which they are familiar;
2. Elements and compounds easily identified on the labeling;
3. Products that contain a diversity of elements; and
4. Attractive packaging.

To facilitate this “direct contact” with the elements in Activity One and Two, the data map, one of Tufte’s (1983) exemplary graphic designs, was incorporated in the lessons. In Activity One students created two data maps, one recording element colors, and a second recording element phases. In Activity Two students created data maps for three different products, recording the biological relevance of the elements in each using the Periodic Table of the Elements for Biology (Orr, 1997). The use of the periodic table as a data map in these two activities exemplified the “active teaching” concept described by Woodgate (1995): “The key is active teaching of the subject, using as a template the periodic table, that powerful tool that features far too little in most first-year courses” (p. 622). The use of the periodic table as a data map in these activities was very similar to Cherif, Adams, and Cannon’s (1997) “Plain Periodic Table Learning Activities,” in which students recorded their research findings on a grid-only version of the periodic table.
As discussed above, the first three activities of the unit study were specifically designed to help students make many meaningful connections to the elements, their location on the table, properties, and everyday occurrences and applications. This in turn facilitated their abilities to “chunk” the elements into meaningful groups, and discover many periodic patterns and the concept of periodicity.

**Reasons #2, #5, and #6: Periodic Patterns Are Complex; Graphics Representing These Patterns Can Be Visually Overwhelming, and Learners Have Difficulty Relating the Meaning of These Graphics to the Structure of the Periodic Table**

These three reasons are grouped together in this section because the case can easily be made that when they are considered as blocks, one on top of the other, they create a conceptual barrier or wall that students must scale cognitively, in order to understand periodicity. The first block in this wall is described by Goh and Chia (1989), Goth (1986), and Volkman (1996), who together contend that the patterns present within the periodic table are complex. Volkman (1996) states that, “There are at least two good reasons for students’ lack of understanding [of the periodic table]: First, the particles composing each element are invisible, and second, the properties associated with these particles follow a complex pattern” (p. 37). Goth (1986) reports, “The concepts are sophisticated, and it is difficult for beginning students to grasp, simultaneously, their meaning as well as their relationships to the periodic table” (p. 836). Goh and Chia (1989) add, “The similar but nonidentical properties of elements in the same group further complicate the situation” (p. 747).

The difficulties students face in comprehending the complexity of periodic patterns are further exacerbated by the instructional use of abstract and complex graphics to display these already complex patterns (Goth, 1986; Osorio, 1990). This is the second block in the conceptual barrier or wall to understanding. Goth contends,
The amount of data is [sic] vast and it is usually presented in table form or in traditional two dimensional line graphs. In both cases, the periodic behavior may be lost in the details of the data. How is a beginning student to see the ‘forest’ of periodicity among the ‘trees’ of 103 electron configurations arranged in a table? (p. 836)

Osorio (1990) similarly states, “The periodic tables in current use have been overloaded with physical and chemical data that, though of high practical value, in attempting to provide the maximum usefulness have unwittingly masked the didactic character that the table inherently possesses” (p. 563).

The third block in the conceptual wall is that students have difficulty relating these complex periodic patterns presented on instructional graphics to the underlying structure of the periodic table. “A graph of molar volume versus atomic number does show a series of bumps and is said to illustrate periodic behavior. But many students have considerable difficulty relating this graphical information to the structure of the periodic table” (Goth, 1986, p. 836).

Tentative explanations for this apparent difficulty that students have in learning periodicity in general, and using traditional graphics in particular, can be derived from meaningful learning theory, cognitive science research, and Solso’s (1994) theory of visual cognition. From a meaningful learning perspective, the traditional periodic table, regardless of whether it is in the most basic form with atomic number, atomic mass and symbol, or one of the more data-laden versions, has, at least initially, almost no meaning to beginning chemistry students, and, as Volkman (1996) states, “...may as well be written in hieroglyphics” (p. 37).

Even if these traditional graphics have some degree of meaning for students, the ability to analyze these graphics is limited by their visual processing capabilities. Much of the data related
to periodic trends is presented to students as numbers in the element boxes of the periodic table (i.e., values for ionization energy, electronegativity). In order for students to “see” the respective periodic trends, they must scan up and down the groups, and across periods. Scanning down a group of elements translates into processing 6 to 7 values, putting the learner near the maximum of their short-term memory capacity of 7 plus or minus 2 bits of information (Miller as cited in Bruer, 1993). Scanning the 8 to 18 values across a period exceeds this short-term memory capacity. Solso (1994) and Tufte (1983, 1990) both report that our eyes fatigue quickly during scanning processes like this, especially when the element blocks are “overloaded with physical and chemical data” (Osorio, 1990, p. 563). Therefore, it would seem very difficult for students to “chunk” numerical information that has limited meaning into meaningful patterns during tasks that exceed their visual processing capabilities.

The preceding discussion illustrates why reasons #2, #5, and #6 are all very much related, and demonstrates the need for the identification and/or development of graphics for instruction that are in greater harmony with the principles of meaningful learning theory, cognitive science, and the theory of visual cognition. Tufte’s theory of graphical excellence guided the selection and construction of graphics for this unit study, and it is complementary to the previously mentioned theories.

The foundational principle of Tufte’s (1983) theory is to use simple, but powerful, graphic designs that efficiently and effectively illustrate complex concepts or relationships. The pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), with actual element photographs, was chosen for use in this study because it clearly exemplifies this principle, and incorporates two of Tufte’s recommended graphic designs, the small multiple graphic and the multifunctioning graphical element (MFE). The pictorial table is both rich with data and meaningful, because of its
visual format. It does not overwhelm the learner with massive amounts of abstract numerical data to process and analyze. Its meaningfulness facilitates visual processing (Solso, 1994) and reduces the demand on working memory because the “chunking” process is also enabled (Miller in Bruer, 1993). Its simple but powerful design (Tufte, 1983) proved to be efficient and effective in helping students “see” the complex patterns of periodicity. This form of the periodic table, on which periodic patterns are visually evident, also answers Campbell’s (1989) call of, “Let us make the table periodic.... Let us make the periodic table of the elements live up to its name.” (p. 739).

Solomon and Bates (1991) state in reference to one of the forms of the pictorial periodic table (Time-Life Books, 1987), “The Royal Society of Chemistry ‘Periodic Table of the Elements’ poster with its photographs of the elements continues to attract the attention of practically everyone who passes by the chemistry department bulletin board” (p. 991). One of the objectives of this research was to observe what happens when this very instructionally valuable form of the periodic table is moved down from the “bulletin board” and placed into the hands of students. Due to its potential to enhance learning, students were given several opportunities to use it during the unit study.

In Activity One, the pictorial table (Menzel, 1991; Time-Life Books, 1987) served as a meaningful introduction to both the elements and the periodic table. As students were encouraged to make observations and look for patterns, the element photographs had immediate meaning as they scanned the table and “saw,” rather directly, element characteristics and properties (i.e., silver metals, yellow nonmetals, colorless gases, etc.). Even elements with which they were not familiar had some degree of meaning in this context.

Activity Four was designed to help students “see” the concept of periodicity, as it is simply and visually evidenced by the pattern of repeating physical and chemical properties of the
elements (reactive silver metals covered in oil, silver metals, colored and colorless nonmetals) appearing on the element card photographs. As stated previously, students are often introduced to periodicity using complex and abstract graphics which illustrate the more abstract and complex periodic patterns such as ionization energy, electron affinity, and so forth. Therefore the use of pictures, in the place of numbers, made more efficient and effective the visual processing of the element data, and the chunking of this information into meaningful patterns. The pilot study indicated that students identified many different patterns among the initial line-up of the element cards in Activity Four. After students first had an opportunity to experience periodicity in a more meaningful context, they then used the traditional graphics to learn the more abstract periodic trend of atomic radius.

**Reason #4: Students Are Unskilled in Identifying Periodic Patterns**

Reason #4 is based on Goh and Chia’s (1989) statement that, “Students have not had enough experience to develop guidelines for determining how, or to what extent, a repeating pattern can be considered periodicity” (p. 747). Activity Four was the culminating activity of the unit study and particularly addressed this concern. It did so by using potentially meaningful graphics and analogies to facilitate students’ visualization and recognition of the repeating “chunks of elements” that are the pattern of periodicity. Activity Four was similar in design to the activities described by Bolmgren (1995), Goh and Chia (1989), Tejada and Palacios (1995), and Irons (1989), where students develop an element classification system. Bolmgren (1995), Goh and Chia (1989), and Tejada and Palacios (1995) have students develop this system using objects that represent the elements (cardboard circles, element cards displaying either atomic size, electron configuration or valence electrons). Irons (1989) use of actual element samples would seem to make this type of activity the most meaningful and concrete of the four. Activity Four of the unit
study simulated Iron’s (1989) activity by the use of element cards with the photographs of the elements from the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987). The procedure for Activity Four was very similar to the one used in Bolmgren’s (1995) activity, in which a guided discovery approach was used to help students reconstruct the cards into the rectangular format of the periodic table. The analogous periodic relationships that exist among the days of a calendar month (Goh & Chia, 1989) were used to reinforce students’ conception of the periodic patterns that they saw in the element cards.

This researcher first conceived the idea of designing an instructional activity in which students used element cards to recreate the periodic table, during the research and writing of a paper for his master’s degree. During this research phase, the researcher learned that Mendeleyev discovered the concept of periodicity using a set of element cards (Graham, 1983; Ihde, 1964; Leicester, 1961; Strathern, 2000). It was also discovered that Mendeleyev used familiar patterns in the card game “patience” (solitaire) analogically to organize his element cards, which led to his discovery of the repeating patterns of periodicity (Graham, 1983; Strathern, 2000). In his unpublished paper, this researcher proposed the development of an activity in which students use element cards with actual photographs of the elements to reconstruct the periodic table. The reason for the addition of photographs of the elements is to help compensate for students lack of knowledge of the elements. The Simulator: Development of the Mendeleyev Periodic Table (Wright & Mitchell, 1998), which also utilizes element cards to recreate the periodic table, was previously considered for use in this research study. It was rejected because of the visual processing demand that would be required of students, as it contained only numerical data for the elements.
Development of the Periodic Table Literacy Rubric (PTLR)

The PTLR (Appendix A) was developed to assess students’ understanding of the elements, structure, and periodicity of the periodic table, and any possible progression in this understanding, as they participated in the four activities of the unit study. The PTLR was initially developed using the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy (AAAS, 1993). Revisions were made after the pilot study to include instances from the history of science and the results of the pilot study. The following discussion will identify the rationale for each level of literacy identified on the rubric.

**Level 0 - Boylian Level of Understanding (1661 - “Did Not Know What One Was”)**

This level is named in honor of Robert Boyle, who is credited with theoretically defining the concept of element as we know it today. However, according to Strathern (2000), Boyle “didn’t actually know what one was” (p. 179). Correspondingly, at this level on the rubric, students show no degree of familiarity with the periodic table, and cannot name any of the elements correctly.

**Level 1 - Lavoisierian Level of Understanding (1789 - “List of Elements”)**

This level is named in honor of Antoine Lavoisier, who in 1789 was one of the first to publish a list of elements. Of the 33 elements identified on his list, eight were compounds and two were forms of energy. Similarly, at this level on the rubric, students can identify some of the elements of the periodic table, but may confuse elements with compounds as did Lavoisier. The pilot study revealed that the majority of students in the class initially had problems distinguishing elements from compounds. Both the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy (AAAS, 1993) state that students should understand there are
over 100 elements out of which everything is made. One student was identified at Level 1 at the beginning of the pilot study.

**Level 2 - Davian Level of Understanding (1807 - “Element Discoverer”)**

This level is named in honor of Sir Humphry Davy, the discoverer of five metals. At this level students can identify one or more of the physical properties of the elements (metal/nonmetal, solid/liquid/gas, colors). There is no benchmark as such in the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy, (AAAS, 1993) however, it has been added because it represents prerequisite knowledge for a Level 3 understanding. Students must first understand the concept of physical properties before they can understand the grouping of elements based on physical properties. Two students were identified at Level 2 at the beginning of the pilot study. A third student, who began at Level 1, ended the pilot study at this level.

**Level 3 - Dobereinerian Level of Understanding (1829 - “Law Of Triads”)**

This level is named in honor Johann Wolfgang Dobereiner, who is thought to be the first to classify the elements into groups having similar properties (Ihde, 1964; Kauffman, 1969; Strathern, 2000). At this level students understand that the periodic table is comprised of groups or families of elements with similar physical properties. The Benchmarks for Scientific Literacy (AAAS, 1993) state this in the form of a benchmark at the middle school level. The National Science Education Standards (NRC, 1996) identify this level of understanding at the high school level in their “fundamental concepts and principles” which include periodicity.

**Level 4 - Pre-Mendeleyevian Level of Understanding (Pre-1869)**

Based on the results of the pilot study, this level identifies an intermediate stage of understanding of the periodic table. At this level students have an understanding of the
organization of the periodic table that goes beyond the identification of groups. Also at this level students may be able to identify various periodic trends. However, the defining characteristic of this level is that they cannot yet communicate the complete concept of periodicity. For the purpose of this study, periodicity was defined as follows: When the elements are listed in order of increasing atomic number, repeating sequences (periods) of elements appear, revealing groups of elements with similar physical and chemical properties. In the pilot study, one of the three students could communicate a partial understanding of periodicity, as defined above, and therefore ended the study at this level of literacy. For this reason it was proposed that this level on the rubric may represent a critical juncture in understanding the periodic table.

**Level 5 - Mendeleyevian Level of Understanding (1869 - “Discoverer of the Periodic Table”)**

This level is named in honor of the Russian chemist Demetri Mendeleev, who is credited with the discovery of the periodic table and its underlying concept of periodicity (Bouma, 1989; Kauffman, 1969). At this level, students can communicate an understanding of periodicity that includes all the components of the definition described in the previous section. As stated in the introduction, periodicity is a very difficult concept, however, the National Science Education Standards (NRC, 1996) and the Benchmarks for Scientific Literacy (AAAS, 1993) each list an understanding or benchmark that identifies it as a concept basic to scientific literacy and one that every student should know. The Periodic Table concept map (see Appendix O) was developed by the researcher and members of his doctoral committee, and graphically illustrates the Level 5 conceptual understanding of the periodic table that students will be challenged to achieve by the end of the unit study. One of the three students ended the pilot study at this level.
RESULTS AND DISCUSSION

Student Conceptions of the Elements, Structure, and Periodicity of the Periodic Table After Interview One (Preinterview)

Throughout this chapter, the six students of the sample from Pine High School are referred to as S1, S2, S3, S4, S5, and S6. In this sequence the students are rank-ordered according to the chemistry grade they had at the beginning of the study (i.e., S1 had the highest average and S6 had the lowest average). The female members of the sample are S1, S2, S4, and S5; and S3 and S6 are the male members. Near the end of the chapter, the six students of the sample from East High School are referred to as CS1, CS2, CS3, CS4, CS5, and CS6, following the same rank-ordering sequence as used for Pine High. The female members of this sample are CS1, CS2, CS3, CS4; and the male members are CS5 and CS6.

Elements – Table L1

When asked “What is an element?” students had an interesting variety of responses ranging from, “It’s those things on the periodic table” (S2) to “What everything else is made of” (S1) to “I forgot” (S5). The element survey and Interview One both indicated that students were generally familiar with element names and symbols. On the list of elements and compounds, they identified all four of the single element names and 33% of the element names in the compounds on the list. As a group, they also provided 80% of the symbols for the elements on the survey.

However, the survey revealed that the students had little real-life knowledge of the elements, were not very familiar with what they looked like physically (descriptions, 18%), or where they could be found and/or used (occurrences or uses, 23%). This indicates that the concept of element had very limited meaning to students apart from the
context of element symbols. In a way, their understanding was like that of Robert Boyle, who had an abstract idea of the elements, and “didn’t actually know what one was” (Strathern, 2000, p. 179).

**Physical and Chemical Properties - Table L2**

The interview revealed that all of the students were familiar with the terms *metal* and *nonmetal*, most were familiar with some form of the term *reactive*, and half of them were familiar with the terms *gas* and *liquid*. However, when students were asked directly for examples of physical and chemical properties, three (S1, S2, S6) did not provide all of the previously mentioned examples they knew, and two (S3, S4) did not provide any of the examples that they knew. Although they knew examples of the properties, they did not know they were examples of properties. They had not conceptually “chunked” (Bruer, 1993) these examples under the subsumer (Mintzes & Wandersee, 1998a) or organizing concept of physical and chemical properties.

In the element survey, students were asked to “Describe what the element physically looks like.” which is reported in Table L1 as element descriptions. Students gave descriptions for 20% of the elements, indicating that for the most part, they did not know what the survey elements looked like. S2 said this directly in the interview, “I don’t know what they (elements) look like physically.” Goh and Chia (1989) state that students should be familiar with a minimum of 20 elements and their properties before they can identify patterns. The interview and survey indicated that although these students were familiar with some of the examples of element properties, they had not made this connection to the elements on an individual basis, and probably were not familiar with the number of elements and their properties that Goh and Chia recommend.
**Group or Families – Table L3**

Based on the results of the previous two sections and Goh and Chia’s (1989) element and property familiarity recommendation, it was no surprise that these students had a very limited understanding of the conceptual pattern of groups and families. Table L3 shows that only two students could correctly define the concept of group or family, and one of those was very weak. Only three could identify group numbers as such, and only two included the term *group* on their concept maps (Figure D1 & D2). S1 and S6 identified the most examples of groups or families, and more importantly were the only students who could identify a characteristic physical property of a group or family. The three students (S1, S2, S6) who had the most well-developed knowledge of physical properties (identified both metals/nonmetals and phases) also had the best understanding of groups or families (identified term *group* and could list at least two examples). So again, the overall lack of understanding of groups or families can be traced to students’ limited meaning for the concept of element, and their lack of knowledge of the physical properties of individual elements.

With most of the students having such a limited knowledge of the key concept of *group*, it was surprising to note that the four students who did not include the term *group* on their concept maps did include information about the sublevel blocks (Figure D3, D4, D5, D6). This seems to indicate that the instruction these students received prior to the study emphasized breadth rather than depth.

**Structure of the Periodic Table - Table L4**

One of the most basic organizational patterns on the periodic table is the separation of metals and nonmetals by the zig-zag line. Interview One revealed that
although students were familiar with the terms, they knew very little about this pattern.

All six students knew that there was a zig-zag line on the periodic table, and four of these six reported that the elements were grouped into metals and nonmetals. However, only three students could correctly draw the zig-zag line, and only one knew the precise meaning of it (to separate metals from nonmetals). This finding also helps explain students’ limited ability to identify the physical properties of individual elements, and their lack of understanding of the concept of group.

Another basic pattern is the organization of the elements into vertical columns called groups, and into horizontal rows called periods. Student knowledge of this area was even more limited. Only three students identified the numbers across the top of the periodic table as groups, and two of these three were the only students who could identify the numbers down the side of the periodic table as periods. One of these three (S2) actually stated that the periodic table was organized into groups, periods, and rows. However, when she was asked what groups and periods were, she could not identify them.

Students also described two other organizational patterns on the table. Table L4 shows that the majority of students had some level of understanding of the sublevels. Most also knew one of the prerequisite concepts of periodicity, that the elements are organized by atomic number.

**Periodicity and Periodic Law**

Of the six students, only one (S2) had even heard of the term *periodicity*, and she could not define it. *Periodic law* was a term that was more familiar, with four of the six students having heard of it, and three students attempted to provide a definition. S2
simply knew that periodic law had something to do with the elements. S5 had a legalistic conceptualization, and stated that the periodic law tells you “what you can do with the element and what you can’t do with the element.” At the end of the interview, only one student (S1) had a correct conceptualization of periodic law, and as discussed next, she developed it during the interview. This lack of understanding of periodicity/periodic law can be attributed to the students’ limited understanding of the prerequisite concepts of physical properties and groups/families.

**Students’ PTLR Ranking After Interview One**

At the conclusion of Interview One, all six students in the sample had met the criteria for Levels 1 and 2 on the PTLR. On the list of elements and compounds provided during Interview One, each student correctly identified all four of the single element names on the list, and a minimum of three of the element names contained in the compounds on the list, and therefore met the criteria for Level 1 (Table L1). Each student also identified the physical property of metals and nonmetals, which met the criteria for Level 2 (Table L2). The assessment of each student’s highest PTLR level will be discussed next.

**Student S1**

In addition to Levels 1 and 2, S1 also met the criteria for Levels 3 and 4. She met Level 3 by correctly defining group or family (elements with similar physical and chemical properties), identifying four families (alkali metals, alkaline earth metals, halogens, noble gases), and the properties of two of those families (halogens-gases, react with metals; noble gases-stable, have a full p sublevel) (Table L3). She demonstrated a
Level 4 understanding by stating that the periodic table is additionally organized by atomic number and by periods (Table L4).

Near the middle of Interview One, S1 stated separately the two main components of periodicity (listing of the elements by atomic number, organizing of the elements into groups with similar properties). Further questioning indicated that these components were conceptually separate in her mind, and that she had not yet synthesized them into an understanding of periodicity. Mintzes and Wandersee (1998b) and Trowbridge and Wandersee (1998) refer to such periods in which students have difficulty acquiring a superordinate concept like periodicity as a critical juncture. One of the three students of the pilot study (Appendix B) was also identified as being at a similar stage. There is also a historical corollary to this juncture in the learning of chemistry. Prior to the discovery of the periodic table, Mendeleyev and contemporaries who were working on the development of a classification system were also at a similar stage (Strathern, 2000).

The following dialogue demonstrates that S1 initially entered Interview One at Level 4, and across the course of the interview she made the above synthesis, and developed a tentative, but basic understanding of periodicity, therefore exiting the interview at Level 5.

R: What are some of the different ways that elements are grouped, organized or classified on the periodic table?
S1: They are organized; to me it looks like they are organized by their atomic number. And they are grouped by their properties I think, because… in a group they have more in common, than across a period with other elements.

(Later in the discussion about that question)

R: Okay, you said they are organized by atomic number, and they are grouped by their properties. Is there a connection between those two things that you know of?
S1: A connection?
R: A connection between being organized by their atomic number and being grouped by their properties?
S1: Umm. (Pause) Maybe because, if they were scattered and they are organized by their atomic number, then when you look at them, like if 18 was way over here by 37, and 43 was over here in the place of 18, then they would not be grouped according to their properties.
R: Is that something that you have thought about before?
S1: No.

(Later in the interview)

R: What is periodicity? Have you heard that term before?
S1: I don’t think so.
R: How about periodic law?
S1: Yes I’ve heard of that, but I don’t particularly, we just had a test on that, and that is the one question I know I got wrong.
R: But you have heard of periodic law?
S1: Yes.
R: You are not sure what it is?
S1: I think it’s the way the elements are arranged according to their atomic number and their physical and chemical properties. I don’t know.
R: Now what do you mean by that?
S1: By law, I guess, the elements are arranged by atomic number, and when they are arranged by atomic number they are automatically just fall into, right by elements that have the same physical and chemical properties as they do, I guess.
R: Have you thought about that before now?
S1: No.

This synthesis is also illustrated in S1’s concept map (Figure D1), in which she has the following conceptual chain, “Periodic Table is grouped by the periodic law, is organized by atomic number, then they fall into families or groups.”

**Student S2**

At the conclusion of the interview, S2 was at a Level 2 on the PTLR, although she had some knowledge of Level 3, 4, and 5 criteria. Related to Level 3, she mentioned the family names of halogens and noble gases, but could not define group, and did not know what noble gases were (Table L3). On her concept map, (Figure D2) she links halogens and noble gases under element types, rather than groups. She mentioned that halogens
were salt formers, but could not elaborate further. Related to Level 4, she stated that the elements were organized by periods (Table L4). However, she could not define period. Related to Level 4 and 5, she reported that the elements are organized by atomic number (Table L4).

Student S3

S3 also concluded the interview at Level 2. He was familiar with several Level 4 and 5 concepts, but he did not demonstrate an understanding of the Level 3 concepts of groups or families. The term group was not included on his concept map (Figure D3). Groups or families were defined as metals, nonmetals, and noble gases; and he used the term block instead of group (Table L3). Related to Level 4, he labeled the s, p, d, f blocks on the periodic table, and related to Level 4 and 5, he stated that atomic number increases left to right (Table L4).

Student S4

S4 also concluded the interview at Level 2 with a very limited knowledge of Level 3 and 4 concepts. At Level 3, she defined group or family as the s, p, d, f (Table L3). Although S4 mentioned the alkaline earth metals, and stated that group 8 doesn’t react with other elements, she did not identify physical properties of either one (Table L3). At Level 4, she labeled the s, p, d, f blocks on the periodic table (Table L4).

Student S5

S5 concluded Interview One at Level 2 with the most limited knowledge of Level 3, 4, and 5 concepts. At Level 3, she defined group or family as elements that can work together, and provided no examples of groups or families (Table L3), and did not use either term on her concept map (Figure D5). At Level 4, she color-coded the s, p, d, f
blocks, and although she mentioned s, p, d, she did not label them as such (Table L4). She stated that the elements are arranged in order of atomic number (Levels 4 and 5, Table L4).

**Student S6**

Like S1, S6 also met the criteria for Levels 3 and 4 of the PTLR, and therefore completed the interview at Level 4. For Level 3, although he provided a very primitive definition of group (elements put together in a certain place with something in common), he went on to identify group numbers and three families (AM, AEM, NG), and provided one or more chemical properties for each of these families, and a physical property of one of the families (Table L3). He demonstrated a Level 4 understanding by labeling the s, p, d, f blocks, and some of the s, p, d, f sublevels on the periodic table (Table L4). Additionally, he indicated he has a partial understanding of Level 5, as he stated that the elements are ordered by atomic number (Table L4). He was however, unfamiliar with the concepts of periodicity/periodic law.

**Student Conceptions of the Elements, Structure, and Periodicity of the Periodic Table After Activity One**

**Physical and Chemical Properties – Table L5**

Interview Two revealed that students greatly expanded their knowledge of the physical properties of the elements as a result of Activity One. Comparing the category of physical property of Table L2 with that of Table L5, we see that most students have “chunked” color, phase, metal/nonmetal under the subsuming concept (Mintzes & Wandersee, 1998a) of physical property. The concept maps of all six students (Figures D7-D12) illustrate that each has “chunked” the terms solid, liquid, and gas under the concept phase. They not only learned that color and phase were physical properties, but
also learned to identify the patterns associated with each on the periodic table. Most importantly, they learned the general characteristics of metals and nonmetals with regard to phase and color (i.e., metals are silver solids; nonmetals can be different phases and different colors).

**Group or Family – Table L6**

Students’ understanding of the concept of group or family was also much more developed at the conclusion of Activity One. A comparison of the first two rows of Tables 3 and 6 reveals that five of the six students (two previously) could define group or family in terms of similar properties, and five of the six could identify group numbers as such. All six students used either group or family as a subsuming concept on their concept maps (Figures D7-D12), whereas only one did so in the first interview. A comparison of the remaining rows of Tables 3 and 6, which display the examples of groups and/or families that students gave, reveals a number of patterns. Each of the six students provided examples using both group and family designations, indicating that they all understood the similarity of these terms to some extent. All of the students also provided more detail with their examples, particularly about chemical reactivity, and all but one (S1) provided more examples than they had previously done.

It was disappointing that students did not provide more examples of characteristic physical properties of groups. Although their knowledge of physical properties, and examples of physical properties, was expanded through the activity, they did not make the connection between physical properties and the characteristics of groups. This indicates that this concept may have needed more time to be developed in the lesson.
Structure of the Periodic Table – Table L7

As a result of Activity One, students made conceptual gains in two main areas in this category. First, they all learned to correctly identify the location of metals and nonmetals. Table L7 shows that all students could correctly draw the zig-zag line on the periodic table (up from 3) and identify its purpose of separating metals and nonmetals (up from 1).

The second major gain is related to student use of the terms group and family to describe the organization of the table. In the first interview students were primarily familiar with the organization of the table in terms of metals/nonmetals, atomic number, and sublevels. Table L7 illustrates that after Activity One, the majority of students used either or both terms (group, family) to describe the organization of the table.

Students’ Reflections on Activity One

Students’ conceptual progress, as just described, can be attributed to the “direct contact” (DeBoer, 1991) students had with the elements. Their comments on the activity provide insight into why it was effective in developing their understanding of physical properties, groups and families, and organizational patterns on the table.

Part 1: Elements in a Bag

In this part of the activity, students came in “direct contact” with actual samples of elements (Deavor & Deavor, 1995; Marshall, 2000; Solomon & Bates, 1991). They recorded the physical properties of actual samples of common elements. All of the students reported that they liked this activity. S2 and S5 both stated they were able to learn the colors of elements. Other students stated:

S1: “Because we got to see the elements, instead of just reading about them, or having somebody tell us about them.”
S6: “You got to see the elements up close”

S4: “I like being able to try to look at the elements that we use everyday.”

**Part 2: Color the Elements**

In this phase students first used the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), which incorporates two of Tufte’s (1983) graphic designs, the small multiple, and the multifunctioning graphical element. In the activity students created colored coded “data maps,” (also a Tuftian graphic design) of the physical properties of metal/nonmetal, phase, and color. Students all responded very favorably to this activity as well, with most of them mentioning they liked learning about the element colors, and that the colors helped them learn about the patterns on the table, patterns related to physical properties and element groups.

S4: “I learned the different patterns, and the different colors of the elements.

S3: “Well how I can distinguish by the different colors. I know where the metals, liquids, and gases are, and radioactive elements.”

S6: “When we did the phases, it helped me locate where they were.”

S2: “Yes, I liked it because it helped me to find out the different types of elements in their groups, that I never knew about.”

**The Pictorial Periodic Tables**

The student comments below illustrate that the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987) is a simple, but powerful graphic design (Tufte, 1983) that is very valuable as an instructional tool. It exemplifies the popular phrase, “a picture is worth a thousand words,” which in this context could be rephrased, “100 pictures of the elements is worth more than thousands of numeric values representing periodicity.”
R: What are your feelings about those tables (pictorial version), did they help you learn?
S1: They helped me picture them more.
R: Tell me more of what you mean by that, they help you picture?
S1: The element, like, if I want to learn about something it helps that you can picture it in your mind.

S4 and S5 responded similarly to the same question:

S4: Yea. They were easier by looking at the picture than looking at the word itself, because by looking at the picture it’s easier to remember the elements.
R: What do you mean by word?
S4: By just seeing the element names.

S5: “And all the pictures, it’ll make you more interesting… It brings life to the periodic table.”

Students’ PTLR Ranking After Activity One

Student S1

Having ended Interview One at PTLR Level 1, S1 had no levels to gain.

However, a comparison of the tables (Tables L2, L3, L4 versus L5, L6, L7 respectively) and her concept maps (Figure D1 versus D7) from the first two interviews reveals that her knowledge of elemental properties (Level 2), groups and families (Level 3) and the organization of the table (Level 4) was deepened.

Students S2, S3, S5

S2, S3, S5 all entered Activity One at Level 2, being unable to define group or family during Interview One. During Interview Two (Table L6) all three provided a basic definition for group or family, identified several groups and their reactivity characteristics, provided the same example of a characteristic physical property of a group (NG are all gases), and therefore met the criteria for Level 3. Also, having already met the criteria for Level 4 in Interview One (by stating the elements are in order of atomic number), each of these students ended Activity One at Level 4.
**Student S4**

S4 also entered Activity One at Level 2, being unable to define group or family in Interview One. At the conclusion of Activity One, S2 was still unable to correctly define group/family, and unable to identify characteristic physical properties of a group, so she remained at Level 2. She was however, able to identify several groups and their reactivity characteristics.

**Student S6**

S6 entered Activity One at Level 4, and since the activity did not address the concept of periodicity, he also remained at Level 4. However like S1, his knowledge of elemental properties (Level 2), groups and families (Level 3), and the organization of the table (Level 4) was deepened through Activity One, as is illustrated in the tables (Tables L2, L3, L4 versus L5, L6, L7 respectively) and his concept maps (Figure D6 versus D12).

**Student Conceptions of the Elements and Structure of the Periodic Table After Activity Two**

**Elements – Tables L8 and L9**

As a result of Activity Two, student ability to identify element names in compounds improved from 33% (Table L1, row 3) in Interview One to 71% (Table L8, row 5) in Interview Three. Comparisons between similar compounds from these two interviews will further illustrate this increase. Only one student was able to identify phosphorus from a phosphate-based compound in Interview One, versus five of six in Interview Three. None of the students identified oxygen in any of the compounds ending in –ate in the first interview, however, half did so for both phosphate and sulfate in Interview Three. This finding mirrors the results obtained during the pilot study, in which
students’ ability to distinguish elements and compounds was significantly improved after participating in Activity Two.

Students also made numerous real-life connections between the elements and human health during Activity Two. Table L9 and students’ concept maps (Figure D13-D18) show that each student became familiar with at least five nutrient categories, and most students learned some of the patterns of elements associated with the categories. This expanded meaning that students now have for the elements (elements in compounds; nutritional relevance) may have assisted them in subsequent activities in identifying periodic patterns (Goh & Chia, 1989).

**Chemical Properties – Table L10**

Previous interviews indicated that student knowledge of the types of elements that combine to form compounds was limited to the fact that the halogens react with metals to form salts (S1, S2, S3; Table L6) and that the alkali metals react to oxygen and water (S1, Table L6). Table L10 summarizes what students knew after Activity Two. All six of the students learned that metals react with nonmetals to form compounds, and that oxygen reacts with a variety of elements to form compounds (Figures D13-D18). Four of the six students reported learning the reactivity relationship between groups 1 and 7, and between groups 2 and 6. It appears that prior to compound mapping activities in Activity Two, students had some knowledge of the reactivity of individual groups, however they knew very little about reactions across groups. This subsumption (Mintzes & Wandersee, 1998a) of information related to reactivity strengthened their understanding of groups and families, and may have facilitated subsequent learning related to periodicity.
Group or Families – Table L11

A comparison of Table L11 with Table L6 reveals that most students (all but S5) became familiar with one or two new groups and their reactivity characteristics during Activity Two. The single new group that students became acquainted with in Activity Two was group 6. In Interview Three, four of the students (S1, S2, S3, S4) reported that group 6 had elements that were active. Those that had identified it before included it in the category of groups 3-6, which was labeled moderately reactive. All of these increases are attributable to the compound mapping activity that illustrated that compounds were formed between groups 1 and 7, and between 2 and 6.

Structure of the Periodic Table – Table L12

Several students (S1, S3, S6) reported in Interview Three that the elements can be organized by nutritional value (Table L12). Table L9 and students’ concept maps (Figures D13-D18) illustrate that most of the students learned a number of nutrition-related patterns of elements on the periodic table from Activity Two, along with the color schemes associated with these patterns. Some of the patterns also corresponded to particular sublevels (Table L9 and L12), for which students had a minimal understanding previously. Table L4 illustrates, that prior to this activity, most students were generally familiar with the terms s, p, d, f, with several students (S3, S4, S6) being able to label the sublevel blocks, and two students (S3, S6) being able to identify some of the sublevels (1s, 2p, etc.). However, only one student (S6) identified the 4f and 5f sublevels in Interview One. Through Activity Two, three more students (S1, S2, S3) became familiar with the location of the 4f and 5f, and three (S1, S3, S6) became familiar with the 3d (Table L12). This activity not only helped students make meaningful, real-life
connections between individual elements and nutrition, but also between the structure of the periodic table (sublevels in particular) and nutrition.

**Students’ Reflections on Activity Two**

Students responded favorably to all parts of Activity Two. Their comments below provide evidence that the conceptual gains discussed above are attributable to the meaningful learning (Novak & Gowin, 1984) in which they were engaged during Activity Two.

**Part 1: Identifying Element Names From Compounds in Products**

In Activity Two students again came in “direct contact” (DeBoer, 1991) with the elements, but this time in the form of household products, similar to Deavor and Deavor’s (1995) “chemistry learning centers.” In this part of the activity students recorded the elements found in a cereal product and in a multimineral product, along with the compounds associated with these elements. A common response was that they learned there were a lot of elements in household products, with some mentioning oxygen in particular.

S1: That when you look at name of something, sometimes you can tell which elements are made up in it.

S6: “I learned that most of the stuff, like we take has a lot of the elements up in it. The items had a lot of compounds up in them.”

S4: “That in products we have a lot of elements that are from the periodic table. And some elements combine to form compounds that are in the products.”

S3: How all the different elements were in the water, in the cereal, the Sun-Vite. I didn’t know they had zinc and copper and those elements in cereal.

S2: “I learned that oxygen is in most of the compounds.”
R: “How is that?”
S2: “They have –ate at the end of each word, for instance carbohydrate, that’s one, phosphate, that’s one.”
Part 2: Create Element/Nutrient Data Maps Using the Periodic Table for Biology

Students used their list of elements from part 1, and the Periodic Table of the Elements for Biology (Orr, 1997) to create a data map (Tufte, 1983) illustrating the nutrient categories found in each product. The responses below show that students learned of the biological relevance of the elements.

S1: That some are radioactive, some are good for you, some you need more than others, some you don’t need at all. ….That some of the nutrients, the way they are on the periodic table, they’re in patterns according to how much you need them.

S5: With the periodic biology thing it help you to see it better, like if it’s a basic nutrient or not, if you need it or if you don’t need it.

S3: How the different things, like the basic nutrients, micronutrients, and the macronutrients are in everything that we eat or drink, basically.

Part 3: Compound Mapping

In this part of Activity Two, students again used their data from part 1 to create compound maps, a technique developed by this researcher, which graphically illustrates the types of elements that form compounds. This technique was developed using Tufte’s (1983, 1990) theory of graphics. All of the students reported learning that metals and nonmetals combine to form compounds. Most also remarked that oxygen is commonly found in compounds.

S2: I learned that the metals will always be in front of nonmetals. What else? You’re talking about when we had to circle the metals on this side and the nonmetals on this side. …. I learned that metals and nonmetals, they work together to create, to make a compound.

S6: I learned the names of the compounds, when the metals react with the nonmetals. And I learned that a lot of elements react with oxygen.

S4: That most of them (elements), they combine with oxygen to form compounds.

One student stated that she specifically liked the technique of compound mapping.
S5: Cause we got to like, draw the lines to make a compound, to form a compound. We got to really see how far they have to go across the periodic table to work with each other.

**The Periodic Table of Biology**

Students also responded favorably to the Periodic Table of the Elements for Biology (Orr, 1997). They reported liking the color-coding system, and being able to determine the nutritional relevance of the elements.

S3: Yes, it had the colors separating and you can see whether it is a micronutrient, inert, radioactive, trace, basic nutrient.

S4: The color code is easier to have them went they are color coded, instead of just trying to learn them all at once or learn them all together.

S5: Cause it was telling you which ones (elements) were good, telling you which ones were bad.

S6: Well, it shows the basic nutrients, like the stuff that we need, and then show the radioactive, and the stuff we don’t need, and then you can read the label and now if it is good for you or not good.

**Students’ PTLR Ranking After Activity Two**

Tables L8-L11, and the accompanying discussion, illustrate that the students deepened their understanding of the elements and structure of the periodic table at PTLR Levels 1 (recognition of elements), Level 2 (chemical properties of the elements), Level 3 (element groups), and Level 4 (structure of the periodic table). Since Activity Two was not designed to facilitate student understanding of periodicity, S2, S3, S5, S6 all remained at Level 4. Activity Two also did not cover the physical properties of the elements, and therefore S4 remained at Level 2. S5, again, was already at Level 5. So, at the conclusion of Activity Two the students remained at their previous PTLR ranking.
Student Conceptions of the Elements and Structure of the Periodic Table After Activity Three

Elements – Table L13

Students made additional real-life connections to the elements in Activity Three, as they identified key elements in common household products. In Interview Four, most students were able to name several products, along with the featured element in each (Figures D19-D24). Collectively, students named a wide variety of products, with only a few common responses (salt, caulking, bleach). Table L13 shows that students remembered almost all of the five commonly occurring elements, and two students (S2, S6) accurately stated that these elements represented reactive groups.

Chemical Properties – Table L14

A comparison of Table L14 with Table L10 reveals that students added to, and expanded on, their knowledge of reactivity patterns learned in Activity Two. Four students (S3, S4, S5, S6) each learned one or more additional examples of reactions. S4 and S5 each added at least one example from the categories of combining groups (i.e., GP 1 & GP 7). S3 and S6 both expanded on the category related to oxygen (oxygen can combine with either metals or nonmetals). The use of the terms ionic and covalent were used much more frequently and specifically to describe the results of reactions, with all six students using it appropriately at least once (up from its use by three students previously).

Group or Families – Table L15

A comparison of Tables L15 with Table L6 and L11, indicates that five of six students expanded their knowledge of groups during Activity Three. Four (S3, S4, S5, S6) students provided information on at least one additional group, with the group 3-5
cluster being the most common response. Three students (S1, S5, S6) added to their
group descriptions details about the physical properties of the elements (metal, nonmetal,
gases).

**Structure of the Periodic Table – Table L16**

A comparison of Tables L4, L7, L12, and L16 reveals no significant changes in
student understanding in this area during Activity Three.

**Students’ Reflections on Activity Three**

Students responded favorably to Activity Three, and some of their specific
comments about what they learned are presented below.

**Part 1: Identifying Elements in Household Products**

In part 1, students were provided with eight groups of products. They identified
and recorded the featured element in each product, along with its parent compound. Some
student responses were very similar to those given for Activity Two. Students reported
that they learned about many of different elements and compounds in products,
particularly the presence of oxygen. Several responses unique to Activity Three are
included below.

S1: All salts don’t have sodium in it.

S2: Every time that I go to a store I pick up something, I always read the
ingredients to see how many elements are in there.

S5: I liked the fact that we got hands-on with the products. We got to see like
what we was drinking, what was going in our hair. And all kind of stuff that we
use in everyday life.

**Part 2: Compound Mapping**

As they did in Activity Two, students again used their data from the first part of
the activity to create compound maps. In their comments addressing Activity Three, they
made many statements similar to those made previously for Activity Two (metals react with nonmetals, oxygen combines with many different elements). However, they also made statements that indicated that they had learned several other reaction patterns on the periodic table.

S1: That most of the time groups 1 and 7 combine with each other.

S3: I learned that to the left of the periodic table it interacts with the right side of the periodic table. And during that reaction it forms an ionic bond.

S4: Most of them, the way they react it, it’s like highly reactive and active, or metals or nonmetals. ….I guess you find compounds by the reactivity, like group 1 and 2 and 6 and 7.

**Students’ PTLR Ranking After Activity Three**

Each student remained at his/her previous PTLR ranking, just as he/she had after Activity Two, due to the similar content and design of Activities Two and Three.

**Student Initial Reconstruction of the Periodic Table During Activity Four – Table L17 and L18**

Tables L17 and L18 present the patterns that students initially observed and recorded when they viewed the line-up of element cards at the beginning of Activity Four. They generally saw patterns related to the background colors of the element blocks, their most frequently mentioned phase (gas) and their most frequently mentioned family (noble gases). All four of the student groups have one or more observations related to the noble gases, and one common observation among all was the numerical pattern associated with the noble gases in the sequence (eighth element). This common observation may have been facilitated by the visual prominence of the noble gases, which had a black background color and stood out among the other more subtle background
colors. Student groups only indirectly mentioned groups one and/or two (green blocks, highly reactive element, metal in water, green element in a container).

Only one student group mentioned the pattern related to metals and nonmetals in the sequence. There were a number of factors that may have distracted students’ attention away from the colors of the metals. The silver color of some of the metals was not obvious in the photograph, as they were presented in numerous small pieces of irregular shape. Also, the group one and two metals had a vivid green background color (which three of the four groups did mention) and most were in glass beakers or were enclosed in glass (which two student groups mentioned).

After students made their initial observations, they were instructed to create spaces in the line of element cards to highlight visually the patterns they had just observed and recorded. Table L18 displays the variety of sequences that the student groups formed during the first steps of recreating the table. The pilot study students also created a similar variety. After this, students were then guided in the construction of the s and p sublevel blocks of the periodic table. One student was particularly excited as she saw the periodic table reforming on her desk in front of her.

S4: This is our periodic table!
R: What’s that S4?
S4: Come look! We created the periodic table over and again!

Mintzes, Wandersee and Novak (1998) refer to this type of experience as an “ah ha” or “Now I see!” moment in the process of conceptual change.

After students had constructed the s and p sublevel blocks, the concepts of groups, families, period, series, and periodicity were reviewed with them, and the concept of periodicity was presented and discussed for the first time. On the second and third days
following this opening activity, after students first reconstructed the s and p sublevel blocks with the element cards, they then incorporated the d block sublevels and f block sublevels to make both the condensed and the expanded forms of the table.

**Student Conceptions of the Elements, Structure, and Periodicity of the Periodic Table After Activity Four**

**Student Final Reconstruction of the Periodic Table During Interview Five – Tables L19 and L20**

Tables L19 and L20 reveal that at the end of the study, each student had a slightly different “visual picture” of the structural pattern of the periodic table, as each used a different method to reconstruct it in Interview Five. To some degree, almost all of the students used atomic number ordering, sublevels, sublevel blocks, and groups to reconstruct the table; however, the emphasis that was placed on each, and the sequence that was used by each, varied from student to student. S2 used ordering by atomic number as her primary strategy throughout the construction process. Similar to S2, S1, and S6 used ordering by atomic number to start their s and p blocks (to the 4s), but then deviated from that method by completing the sublevel blocks, one at a time, to finish their tables. S3 and S5 both used group and sublevel formation at the onset of construction, and then completed it by filling the sublevels in order of atomic number. S4 was the only student to begin the process by putting all of the elements in a line in order of atomic number, as she did at the beginning of Activity Four. She then constructed her table by forming groups and sublevel blocks from the elements in the line.

**Physical and Chemical Properties – Table L21**

A comparison of Table L21 with Tables L5, L10, and L14, shows that through Activity Four, most students learned an additional example of both a physical property
and a chemical property. Four of the students gave all or part of the correct pattern for the physical property of atomic size. Students recreated this pattern in Activity Four using paper strips representing each period, with the atomic size of each element being represented by a circle of proportionate size. All but one (S5) discussed the chemical property of oxidation number, and two (S2, S4) discussed the chemical property of outer sublevels. S2 also discussed outer shell electrons, an additional chemical property. The patterns related to these chemical properties was discussed with students after their third day of recreating the periodic table.

**Group or Families – Table L22**

In Interview Five, as in previous interviews, students primarily described the groups and families in terms of their chemical properties. A comparison of Table L22 with Table L15 reveals that students learned new group patterns related to oxidation number, outer sublevels, and outer shell electrons in Activity Four. Five of the students identified the oxidation number for each of the main groups (groups 1-8). S4 also identified the sublevel associated with each group (s or p). S2 provided more detail for each group by also giving the outer sublevel arrangement and the number of outer shell electrons.

**Structure of the Periodic Table – Table L23**

As a result of Activity Four, students’ understanding of the organization of the periodic table was expanded in a number of categories (Table L23 compared with Tables L4, L7, L12, L16). Two students used the term periodicity in their discussions about the organization of the table. All six students were able to identify the period/series numbers as either periods, series or energy levels (up from 3). Also, five of the six students gave a
more well developed definition of period/series than they previously had. When students were asked, “Why is the periodic table shaped as it is?” three responded that if the f block were in the middle it would be too long, and two responded that the purpose of the shape was to group similar elements together. All of these results can be attributed to students’ reconstruction of the periodic table in Activity Four.

**Periodicity and Periodic Law**

Overall the students made significant progress in understanding the concept of periodicity during Activity Four. This is evidenced by the fact that all six students incorporated the term *periodicity* in their final concept maps (Figures D25-D30). Interview Five revealed that two of these students (S3, S5) developed a PTLR Level 5 understanding of periodicity during Activity Four. It also revealed that at the end of the study another two students (S2, S4), like S1 in Interview One, a pilot study student (Appendix B), and the chemists of Mendeleyev’s time (Strathern, 2000), were at a critical juncture (Mintzes & Wandersee, 1998b; Trowbridge & Wandersee, 1998) in the learning of periodicity. As will be seen next, in the discussion of each individual student’s final understanding of periodicity, these two students had a prerequisite understanding of the two component concepts, but had not yet integrated them into an understanding of periodicity.

**Student PTLR Ranking After Activity Four**

**Student S1**

S1 ended this study where she began, at Level 5, however, she presented a much more confident definition of periodicity than she did in the first interview.
S1: They grouped them by atomic number, increasing atomic number from left to right, and when they do that they fall into groups with similar physical and chemical properties.

**Student S2**

S2 entered and exited Activity Four at Level 4, being unable to define periodicity.

She described the two main components of periodicity in a single sentence initially; however, at the end of the discussion, it is evident that she had not yet synthesized the two into an understanding of periodicity.

R: What is periodicity or periodic law?
S2: It’s the increasing atomic number, and it helps you to, it is something dealing with similar elements, all the similar elements are in the same group. I think that’s what it is? I know I’m close to it.
R: Which term means more to you, periodicity or periodic law?
S2: Periodicity, because we went over that more.
R: Now you said increasing atomic number.
S2: Yea.
R: Similar elements are in the same group.
S2: Yea.
R: Is there a connection between those two things you told me?
S2: Not that I can think of right now.

**Student S3**

Early in Interview Five, S3 stated both components of periodicity separately.

R: Are there any patterns on the periodic table related to electron configuration?
S3: Yea, the atomic mass, how it increases from left to right. I think that’s called periodicity.

R: What are some of the different ways that elements are grouped, organized or classified on the periodic table?
S3: They are grouped in families, like they have similar properties basically. That’s how they are organized. Because of their similar properties.

Later in the interview, S3 demonstrated that the components were integrated into an understanding of periodicity, although he used the term atomic mass instead of atomic number.
R: What is periodicity?
S3: How the elements, are like, the increasing atomic mass, how the elements are grouped, and the electron configuration.
R: …Increasing atomic mass and how the elements are grouped, is there a relationship between those 2 things?
S3: Yes. ….The mass determines the electron configuration, and that’s how they are grouped, cause if your number is like, 1 or 2, 3. ….Like hydrogen, helium, lithium, and, those are the atomic mass, and when you do the electron configuration, you start with the atomic mass. ….And it really just falls into place, the atomic mass, into groups (group 1, 2), and …into that energy level, and once it falls into that energy level you can then use the electron configuration to figure out the element’s position on the table.

Student S4

S4 entered Activity Four at Level 2, and left it at Level 4. She provided a basic definition of group, demonstrated a well-developed understanding of the chemical properties of various groups, and described the physical properties of group 1, and therefore attained a Level 3 understanding. She also described the arrangement of the periodic table in terms of energy levels and sublevel blocks, and so she met the criteria for Level 4 as well. When asked about periodicity, she provided many of the key details of periodicity in the same sentence, but failed to incorporate the concept of group in her discussion, which was needed for the definition of periodicity at Level 5.

S4: It’s the way elements are arranged by the increasing atomic number, and similar properties.
R: Elaborate on that for me, the way elements are arranged by increasing atomic number and similar properties. What do you mean by that last part there?
S4: As you go from left to right, the atomic number increases, and they are also arranged by, like the phase, whether they are metals or nonmetals, and color.
R: Now is there any connection between the elements being arranged in atomic number and the similar properties. Is there a relationship between those two things, or just kinda coincidental
S4: I guess a relationship.
Student S5

S5 remained at Level 4 after Activity 4, also being unable to demonstrate an understanding of periodicity. When asked about it in Interview Five, she made the following statement.

S5: Periodicity is when a nonmetal and metal What did he tell us yesterday? When a metal and nonmetal I think react with each other.

Student S6

S6 ended the study at Level 5, moving up from Level 4. Although stated tentatively, he gave the definition of periodicity very simply and accurately.

S6: I think that’s how the elements are ordered by they atomic number to form their families and their series, I think.

Student Reflections on Activity Four

In Activity Four students reconstructed the periodic table using cards that featured photographs of the elements. Students generally responded favorably, with student comments ranging from “okay” to “cool.” S1 indicated that the coolness of the activity was in comparison with other more traditional ways of learning science.

S1: Yea, it was cool.
R: What made it cool, what did you like about it?
S1: You didn’t have to sit there and listen to somebody lecture.

Four students stated that they liked the activity because they got to recreate the table.

S4: We had to put the table together ourselves.
S6: Oh, because I wanted to see could I put the elements together like the periodic table without looking at the chart.

Students’ Favorite Activity of the Unit Study

When asked what their favorite activity of the unit study was, five of the six students chose Activity Three, as did all of the students in the pilot study. It is commonly
referred to as “Products in a Bag,” as students identified elements from products sorted into plastic bags.

S2: Because it helped me to learn what elements are in the products we use in everyday life. And now when I go to the store, every time I pick up something I read the ingredients.

S3: Because you get to work with like your household things that you use at home, and you can like relate to it, like you do it at school, and you can go home and also look at different things and find elements.

S5: Cause we got to work hands-on with the element.

S6: Because it was interesting working with the stuff in the bag finding out what kind of elements they had up in them.

The remaining student selected Activity Four as her favorite activity.

S4: Because I had just got a chance to put the table together myself.

Students’ Choice of the Activity From Which They Learned the Most About the Periodic Table

Three students chose Activity Four as the one from which they learned the most.

S3: The one with the elements on it. …cause you had to put them (element cards) together.

S2: Cause you had to start from the beginning with the periodic table.

Two students chose Activity One, which featured the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987).

S1: What was Activity One?
R: That’s where we just used the periodic table of pictures, and we used that to learn about physical properties.
S1: I think that one.
R: And why.
S1: Because I can see it.

S4: The picture, the pictorial ….Because, instead of words, it shows you the picture. It’s easier to remember the picture than words.
A comment by S5 in this phase of the interview also provided insight into how students viewed the pictorial periodic table.

S5: It helped me see how the elements looked.

One student chose Activity Two, which used the Periodic Table of the Elements for Biology (Orr, 1997).

S5: With the nutrient, where we got to use the periodic table of biology, because it told us like which elements had nutrients and all that.

Comparison of East High School (EHS) Student Conceptions of the Elements, Structure, and Periodicity of the Periodic Table With Pine High School (PHS) Student Conceptions, After Traditional Instruction on the Topic

Although each chemistry class had a distinct advantage over the other (PHS students covered the topic over an additional 10 class periods; EHS had a teacher with 16 years more experience), these seemed to balance one another out, and they both left traditional instruction on this topic with an almost identical conceptions of the elements, structure, and periodicity of the periodic table.

Elements – Table L24 Versus Table L1

Like PHS students, EHS students had a variety of responses to the question, “What is an element?” Both groups correctly identified all four of the single element names on the list of elements and compounds provided to them. However, the students from EHS were generally more familiar with the elements, as they identified 18% more elements from compound names (Table L24 compared with Table L1) than did PHS students. This can be attributed to the fact that the EHS students had learned the elements prior to taking chemistry.
Physical and Chemical Properties - Table L25 Versus Table L2

A comparison of Table L25 with Table L2 reveals that EHS student knowledge of the physical properties of metal/nonmetal and phase was very similar to that of PHS students. However, the interview revealed that EHS students had no knowledge of the concept of chemical property, although they did discuss an example, the oxidation numbers associated with each group. EHS students, like PHS students, had not conceptually linked their examples of physical properties to the subsuming concept of physical and chemical properties. Only one of the EHS students provided examples of physical properties when asked directly (versus three of the PHS students).

Group or Families – Table L26 Versus Table L3

Overall, EHS students had a very limited understanding of the concept of group or family, like PHS students. Only a few students in each group were able to provide some semblance of a definition of group or family. Several from each group could not identify group numbers as such. Although they provided more examples of groups and families, and more detail with those examples, only two could identify a characteristic physical property of a group or family (like PHS students).

Structure of the Periodic Table – Table L27 Versus Table L4

A comparison of the two tables reveals that neither group, overall, had a clear understanding of the location of metals and nonmetals on the periodic table. Roughly half in each group demonstrated some degree of understanding of the organizational concepts of group/families or periods/series. The students of PHS did have a better understanding of the organization concepts of atomic number and sublevel blocks.
Periodicity and Periodic Law

The interviews with the EHS students revealed that, like the PHS students, they were generally familiar with the term *periodic law*, and unfamiliar with the term *periodicity*. They were also similar in that two students (CS2, CS3) attempted to define *periodic law* (compared to three at PHS). The statements below reveal that both students, particularly CS3, are close to understanding the concept.

CS2: Something about when the elements, it’s like broken down. It’s talking about with the element and the atomic number, and the way it is arranged on the periodic table, I think.

R: Can you tell me why it (periodic table) is shaped the way it is….?
CS3: I don’t know. I just know they (elements) arranged according by their increasing atomic number.
R: Tell me more about that. The elements are arranged by increasing atomic number. Anything else more you can tell me on that?
CS3: They are in groups, different groups and families.
R: ….Now is there a relationship between those two things, do those two things go together, or not?
CS3: Two separate facts.

Later in the interview, she defined periodic law as:

CS3: The quality or state of elements regularly recurrent.

East High School Students’ PTLR Ranking After Interview

All of the students met the criteria for Level 1 on the PTLR, by correctly identifying all four of the single element names on the list of elements and compounds (Table 24). Five of the six students (CS1, CS2, CS3, CS4, CS5) identified the physical property of metals and nonmetals, and therefore also met the criteria for Level 2 (Table 25). CS6 was unable to identify any physical properties, and therefore ended the interview at Level 1 (Table 25). Four (CS2, CS3, CS4, CS5) of the above five were
unable to meet the Level 3 criteria for groups or families, and therefore exited the
interview at Level 2 (Table 26). CS1 met both the Level 3 criteria for groups or families
(provided the characteristic physical properties of several groups, Table 26) and the Level
4 criteria related to the organization of the table (identified periods, Table 27). She was
unable to define periodicity, and therefore exited the interview at Level 4.

**Element Survey Results – Table L28**

The presurvey results reveal that prior to the unit study, the students of the sample
were familiar with element symbols (80%), but much less familiar with the physical
descriptions (18%), and occurrences and uses (23%) of the elements. This same general
pattern was true for the class as a whole. Table L28 shows that, on average, the students
in the sample grew in their knowledge of the physical descriptions (59%) and the
occurrences and uses (29%) of the elements, but grew little (3%) in their knowledge of
the element symbols. Again, compared to the sample, the class had very similar level of
growth. The growth in students’ knowledge of the element descriptions can be attributed
to Activity One and Four, where students used the pictorial periodic table (Menzel, 1991;
Time-Life Books, 1987) to map out the physical properties of the elements. The growth
in students’ knowledge of the element occurrences and uses can be attributed to Activity
Two and Three, where students made real-life connections to the elements by identifying
them in household products.

**Pre- and Posttest Results – Table L29**

The pretest results reveal that going into the study the research sample of students
had some level of knowledge of all the subcategories of the test, with their strongest areas
being electron configuration (64%), reactivity (43%), and atomic structure (40%), and
their weakest area being chemical formulas (18%). This pattern holds true for the class as well, and correlates with the findings of Interview One, in which students reported using the periodic table to do electron configuration, and five of six discussed the concept of reactivity.

The paired t test that was performed on the pre- and posttest data revealed that the difference between the pretest and posttest scores for the class was statistically significant at both the p<.05 and p<.01 levels (t = 5.11, p = .00013). This statistical significance is evidenced and further illustrated by several patterns present in the data. Table L29 shows that all six students in the sample showed growth from the pre- to posttest (ranging from 11% - 47%), and in each subcategory of the test (ranging from 22% - 45%). The class as a whole also showed growth in each subcategory (from 14% - 25%), and the classes’ average growth of 18% was comparable to the sample’s average growth of 26%. The top three gainers in the sample (S1-29%, S3-47%, S6-32%) were also the same three students who ended the unit study at PTLR Level 5, with an understanding of the concept of periodicity.

PTLR Levels of PHS and EHS Students – Tables L30 and L31

Table L30 illustrates the progress that the selected Pine High students made across the unit study. Overall, each student gained on average 1.7 PTLR levels, and this average gain rises to 2.0 PTLR levels if student S1 (who entered the unit study at Level 5) is not included. The students who participated in the pilot study also averaged 2.0 levels of gain across the unit study. Of the six students beginning the study, four can be identified as student “novices” of the periodic table (those at PTLR Level 2 or lower). These four students gained, on average, 2.3 levels, and one of these emerged as a student
“expert” of the periodic table (those attaining PTLR Level 5), along with S6 who began the study at Level 4. The remaining three student “novices” ended at Level 4, and two of those ending at the upper end of Level 4 at the previously discussed critical juncture of learning periodicity. Table L30 also illustrates that all of these PTLR gains occurred during Activities One and Four.

A comparison of line one of Table L30 with Table L31 shows that the students from Pine High School and East High School had very similar PTLR rankings (2.8 versus 2.2) when they completed traditional instruction on the periodic table. This concurs well with the finding of the content analysis, which indicated that both groups of students had a very limited understanding of the key concepts of periodicity.

Summary

This study was a cognitive “corps of discovery” which successfully explored and mapped the unknown territory of how students learn about the periodic table. The vehicle of this expedition was a unit study designed to address the reasons why students have difficulty learning periodicity (Goh & Chia, 1989; Goth, 1986; Volkman, 1996). It incorporated principles from the theories of meaningful learning, expert-novice, graphics design, and visual cognition to help address these areas of difficulty. The effectiveness of this unit study in helping students make the journey to “periodic table literacy” was evidenced in each category of data that was collected. The results summary tables (found in Appendix L and which summarize the qualitative data) and the students’ coconstructed concept maps (Appendix D) document in detail the conceptual landscape of each student at critical points in the journey, as well as the conceptual progress they made overall. The pre/postsurvey gains for the six students were 59% for physical descriptions of the
elements, and 29% for occurrences and uses of the elements, indicating that their knowledge of the elements improved significantly. A pre/posttest gain of 26% was achieved by these students, and pre/posttest gain for the class was statistically significant. Finally, students increased an average of almost 2 levels on the PTLR, with all of the students ending at either PTLR Level 4 or 5. This study, therefore, not only mapped out the previously unknown territory of student learning of the periodic table, but also identified an effective instructional vehicle to help students achieve a standards-based understanding of the periodic table.

Prior to this research, studies involving the periodic table were conducted by Abraham et al. (1994), Bonar (1999), and Lehman et al. (1984). This study answered the call of two of these science education researchers, one who concluded after his study that “additional research is needed with subjects of differing abilities using modified tables to study different content for longer periods of time” (Lehman et al., 1984, p. 893), and another who stated the need for more extensive study of student concepts of the periodic table (Bonar, 1999). The results of this study provide an interesting comparison to those obtained by Lehman et al., and are helpful in the interpretation of the results obtained by Abraham et al. and Bonar.

This study contrasted with that of Lehman et al. (1984) in a number of ways. It included the use of qualitative methods (versus quantitative only) and was conducted over a longer period of time (six weeks versus several days), both of which allowed this researcher to discover student conceptions of the periodic table and document how these conceptions changed over time. One of Lehman’s findings was that lower ability students used a basic version of the table more effectively, and higher ability students used a
graphic version more effectively. This study revealed that all of the participating students (low, medium and high achieving) made significant cognitive gains and achievement gains (as measured by Lehman’s posttest) through the use of a modified version of the table. The differing results between these two studies can be explained by the fact that the pictorial periodic table (with photographs of elements identifying their color, phase and metallic/nonmetallic nature) used in this study was more meaningful than the graphic version of the table (which included additional numerical data and small circles representing atomic size) Lehman used in his study.

Abraham et al. (1994) and Bonar (1999) conducted separate studies which examined student understanding of the periodic table. Both studies challenged students with problems requiring the application of the concept of periodicity in a novel context (fictional periodic table, library classification activity). In each case the researchers reported that students performed poorly on these tasks and demonstrated very limited use of the concept of periodicity. This researcher would predict that the lack of student success on these tasks was due to the lack of conceptual development, as his study showed that after traditional instruction most students have a very limited understanding of the elements and structure of the table, and almost no understanding of periodicity, therefore, tasks which require students to apply knowledge of periodic patterns would be unproductive.
CONCLUSIONS AND IMPLICATIONS

The Main Research Question

The main research question of this study was: How do selected high school chemistry students' understandings of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics?

Both the qualitative and quantitative data show that the students expanded and deepened their conceptual understanding of the elements, structure, and periodicity of the periodic table as a result of their participation in the unit study. The comparison of the selected Pine High students with those at East High provides support for the assertion that the knowledge the Pine High students had of this topic when they began the study is representative of what chemistry students at high-minority enrollment, high-poverty schools in the Deep South have learned after traditional instruction.

Subquestion One - Activities of the Unit Study

The first subquestion of this study was: What do these students learn, incrementally, via each of these inquiry-based, primarily visual instructional activities?

Activity One

Activity One featured the use of the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), and the graphic technique of data mapping. The activity proved to be very productive in developing students’ understanding of the physical properties of the elements. Students learned to identify color, phase, and metal/nonmetals as physical properties, and were able to identify the patterns on the periodic table associated with each of these properties. Also as a result of Activity One, students were able to more
accurately define groups and families, identify group numbers as such, provide new examples of groups, and give more characteristic properties of individual groups. These conceptual gains are also reflected in the increasing PTLR levels of some of the students. Three students rose from Level 2 to Level 4 through this activity, reflecting a new standards-aligned (AAAS, 1993; NRC, 1996) understanding of the concept of group.

The conceptual gains made through this activity can be attributed to students’ “hands-on, minds-on” work with actual element samples, and their data mapping of the colors and phases of elements using the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987). When asked about this activity, students discussed the meaningfulness of the elements’ pictures and samples, and how the use of color helped them learn about the patterns of the physical properties of the elements on the table.

The only disappointment related to Activity One was that students did not make the connection between their new knowledge of physical properties and the concept of groups of elements with similar properties. It was hoped that they would have identified more group characteristics in terms of physical properties (color, metal/nonmetal, phase). To help students make this connection in the future, an additional step will be incorporated at the end of the activity. Students will record the properties of each group on an activity sheet very similar to the one used at the end of Activity Four, which is entitled “Characteristics Of Individual Groups Or Families On The Periodic Table.”

Activity Two

In Activity Two, students identified and analyzed the elements in three nutrition-related products. Through this activity they progressed in their ability to identify elements in compounds as they analyzed the ingredient labels of the products. In the data mapping
phase of this activity, where they used the *Periodic Table of the Elements for Biology* (Orr, 1997), students learned various patterns of elements on the table related to nutrient categories, and that many of these patterns also correlated with the location of sublevels. Students reported that through the compound mapping component of the activity they learned that metals combine with nonmetals to form compounds, and that oxygen is frequently found in compounds. The interviews also revealed that they expanded their knowledge of element groups, the reactivity characteristics of groups, and the reactivity among elements and among groups.

**Activity Three**

Five of the six students chose this activity as their favorite of the four, with several reporting that they liked learning about the products that they use in everyday life. Activity Three was similar in a number of ways to Activity Two, as students analyzed and identified elements contained in compounds in household products, and created compound maps for featured compounds in these products. However, in *this* activity they analyzed the elements in approximately 40 different products. Students identified the five most frequently occurring elements in the products, and learned that these elements represented the four most reactive groups on the periodic table, which helped either to develop or reinforce their understanding of the reactivity characteristics of these groups. The compound mapping phase of Activity Three also helped students expand their knowledge of groups, and reactivity patterns among elements and element groups.

**Activity Four**

The graphic centerpiece of Activity Four was once again the pictorial periodic table (Menzel, 1991; Time-Life Books, 1987), this time in the form of individual element
cards which students used to reconstruct the periodic table. Three of the six students reported that this activity was the one in which they learned the most about the periodic table. The results of the study support this claim, particularly with regard to what they learned about the organization and periodicity of the table. When students first observed the line-up of element cards at the beginning of the activity, they recorded a number of different patterns related to the location of the noble gases and the background colors of the element blocks. At the conclusion of Activity Four, all of the students recreated the condensed form of the table in Interview Five without assistance. During this final recreation of the table, it was apparent that students had become more familiar with the organizational patterns on the table, as they used various combinations of ordering by atomic number, sublevels or periods, sublevels blocks, and groups to reconstruct the table. The one organizational pattern that they learned primarily from Activity Four was the concept of periods or individual sublevels, which they had not discussed previously.

The students made substantial progress in their understanding of periodicity and its prerequisite concepts through this activity. Two students moved from Level 4 to Level 5, signifying their newly acquired understanding of periodicity. Two other students described periodicity in terms of its prerequisite concepts, which they had not done previously. However, they did not demonstrate that they understood the connection between them, and therefore did not yet have a basic understanding of periodicity as defined by the PTLR.

Following the reconstruction phase of Activity Four, students also learned the periodic pattern related to oxidation number, which was presented and discussed along with the patterns for outer sublevel and outer shell electrons. Students then participated in
a second reconstruction activity using cards with small circles, through which they learned the periodic pattern for atomic size.

**Subquestion Two - The PTLR**

The second subquestion of this study was: Is the categorization and tracking of these students’ conceptual progress using the researcher-designed, history-of-chemistry-based, standards-linked, Periodic Table Literacy Rubric [PTLR] helpful to the chemistry teacher and/or these students in monitoring understanding? The PTLR proved to be a very valuable assessment tool throughout the study to evaluate students’ progress in learning the key concepts necessary for understanding periodicity. Its value was realized early in the study when it was used to assess what students had learned from the traditional presentation of the periodic table that they received in their chemistry class. The rubric served as the focal point of a comprehensive analysis of students’ prior knowledge, and revealed that they had a very limited conceptual understanding of the key concepts related to periodicity. Without the objective conceptual standard of the PTLR, this limited conceptual understanding may have otherwise been masked or obscured by students’ familiarization with the vocabulary of the periodic table.

The PTLR’s initial use also revealed that although students understood several Level 4 organizational patterns on the table (ordering by atomic number, sublevel blocks), they had not yet mastered the more basic concepts of physical and chemical properties (Level 2), and groups and families (Level 3). This indicates the PTLR could be useful not only as an assessment tool, but as a curricular tool, as the criteria at the different levels define the standard-based sequence of learning periodicity and its
prerequisite concepts. It could help teachers focus on these key concepts, and the critical level of understanding of these concepts that they must have to understand periodicity.

The second aspect of this question involved an examination of the usefulness of the PTLR to students in monitoring understanding. The original research plan was to provide the PTLR to students during each interview, and have them perform a self-assessment of where they thought they were on the rubric. However, concern arose that this might unintentionally become a “learnable moment,” instead of an “assessable moment,” so it was dropped from the study, lest it bias the results. This concern was justified, as a “learnable moment” occurred during Interview One, when S1 synthesized an understanding of periodicity while responding to the interview questions.

Several modifications to the PTLR are recommended as a result of this study. At Level 2, the ending phrase “by element” would be deleted. This additional qualifier was not applied in the study, and although it would be beneficial for students to be familiar with many elements and their properties, it now appears that students need only to be familiar with the concept of element properties in order to progress to a Level 3 understanding of groups of elements with similar properties. Also, chemical properties would be added to the statement and would read, “Can identify one or more of the physical and/or chemical properties of the elements.” During the study students generally provided characteristic chemical properties of the elements, over the physical properties, however, none of the students were retained at Level 1 for this reason. At Level 3, the descriptor would be modified to directly include chemical properties, and it would read, “Understands that the periodic table is composed of groups or families of elements with similar physical and/or chemical properties.” Again, during the study students generally
provided characteristic chemical properties of groups, over the physical properties, and several students (S4, CS2, CS4) remained at Level 2 as they gave only characteristic chemical properties of groups.

**Subquestion Three - Critical Junctures**

The third subquestion of this study was: Are there critical junctures in the learning of periodicity, and if so, which, if any, of the visual learning activities seem to help students pass such research-identified, "learning checkpoints" successfully? Prior to this study, the research (Abraham et al., 1992; Bonar, 1999; Lehman et al., 1984) that had been done on the periodic table revealed very little about how students learn the concept. However, several educators (Goh & Chia, 1989; Goth, 1986; Volkman, 1996) contended that it is a difficult topic for students to learn. This study provided empirical confirmation of this apparently common experience among chemistry teachers, along with insights into why students have difficulty learning periodicity. Most students entered this study knowing one of the prerequisite concepts of periodicity, that the elements were organized in order of increasing atomic number. However, most students did not have a basic understanding of the second key concept, that of groups of elements with similar properties. In fact, most students did not understand rudimentary physical and chemical properties. Therefore, there are conceptual obstacles in understanding periodicity: understanding properties, and understanding the concept of groups. Even when students did attain an understanding of ordering by atomic number, and the concept of groups with similar properties, they did not automatically synthesize the two into an understanding of the superordinate concept (Mintzes, Wandersee & Novak, 1998) of periodicity, which is the last obstacle. Across this study, four students (S1 in Interview One, S2 and S4 in
Interview Five, East High student CS3 in her interview) were identified as being at this point in the learning process, and therefore provided supporting evidence for this synthesis being designated a “critical juncture” (Mintzes & Wandersee, 1998b; Trowbridge & Wandersee, 1998) in the learning of periodicity.

The reconstruction of the periodic table in Activity Four was instrumental in helping two students (S3, S6) acquire a Level 5 understanding of periodicity, and bringing two more students (S2, S4) to the threshold of understanding the concept. The success of Activity Four can be attributed to the visual and inquiry-based nature of the activity. Through the process of guided discovery or inquiry, students were actively engaged in sequencing the elements in order of atomic number. As they did this, the repeating pattern of physical and chemical properties suddenly emerged before their eyes. The activity familiarized students with the table to the point that all six were able to recreate it in the last interview. However, it appears that if students have not previously developed an understanding of the concepts of the properties and groups of elements, they will be hindered in their ability to develop an understanding of periodicity, despite the meaningful, visual, and engaging nature of the activity.

Implications for the Teaching of the Periodic Table

The interviews with East High students, and the initial interviews with Pine High students, provided baseline data about what students learn when traditional instructional methods (lecture, textbook-based activities) are used to teach the periodic table. In both cases students became familiar with the terms related to the periodic table, but developed a very limited conceptual understanding of the topic overall, and a particularly limited understanding of the key PTLR concepts deemed fundamental for understanding
periodicity (elements, physical and chemical properties, groups), as well as almost no understanding of periodicity. This indicates that the curriculum objectives, instructional methods, and classroom assessments associated with this topic should be re-evaluated, altered, and aligned to increase students’ conceptual understanding.

The finding that students were familiar with terms, but had little conceptual understanding of those terms, suggests that the traditional curriculum’s treatment of the periodic table is “a mile wide and an inch deep.” Therefore, it appears that, in order to achieve the standards-based goal of a deeper understanding of periodicity, teachers should narrow their curricular focus to the key concepts of the PTLR and seek to help students first develop a mastery of these prerequisite concepts.

Students’ limited understanding obtained from traditional instructional methods also indicates that they need to be more actively engaged when learning about the periodic table. The research demonstrated that more meaningful, visual, and inquiry-based activities can increase student interest in, and understanding of, the periodic table. Throughout the study students reported patterns they had learned related to color. This study also revealed that students remembered many of the periodic patterns that they actively mapped out.

The fact that formal instruction on the periodic table left these students with a very fragmented understanding underscores the need for specific formative and summative assessments that more effectively evaluate their learning. This research demonstrates that the PTLR can be an effective tool for such a task.
Implications for Further Research

There are many opportunities for additional research to confirm the results of this exploratory study, and to test its initial knowledge claims and value claims. The study’s findings could be tested with larger groups of students representing additional ethnicities, geographic areas, and school types (urban, suburban). Studies of the current curricular goals of teachers related to the periodic table, and the instructional strategies that they use to teach it, are needed to broaden the baseline data in order to construct an effective transition from current teaching practices identified by this study. Additionally, since the textbook often serves as the entire chemistry curriculum in many rural school settings, a comparative study of the graphic effectiveness of the presentation of the periodic table of the elements in various chemistry textbooks could be of great value.

Additional research to improve the innovative activities in the current unit study might prove beneficial and add to the knowledge base of effective pedagogical content knowledge (PCK) strategies to enhance chemistry learning. The efficacy of these activities with students above and below the level of high school chemistry could also be explored. Activities One, Two, and Three may prove helpful to developing the understanding of physical and life science students at the middle school and junior high levels. Activity Four may also have applications at the community college level. Additional research with the element card activity could explore the learning value added by various graphic improvements in the pictorial form of the elements. For example, how does the presence or absence of the background colors on the cards affect student learning.
As the next step in his focused line of research on teaching the periodic table, the premier thinking tool of chemistry, this researcher plans to pursue the first option proposed in this section: testing the unit activities, the PTLR, and the claims of this exploratory study in various educational settings, as well as developing new rubrics for formative and summative evaluation of students’ progress as they encounter increasingly complex, more multivariate periodic tables, with many more embedded data patterns to first notice and then understand. Mendeleyev's shoulders are broad.
REFERENCES


APPENDIX A

PERIODIC TABLE LITERACY RUBRIC [PTLR]

5 - Mendeleyevian Level of Understanding (1869)
Understands that when the elements are listed in order of increasing atomic number, repeating sequences (periods) of elements appear, revealing groups of elements with similar physical and chemical properties.

4 - Pre-Mendeleyevian Level of Understanding (Pre-1869)
Understands the periodic table is organized in various ways in addition to groups or families (i.e., periods or series, sublevel blocks). May also know many of the periodic trends (i.e., reactivity, oxidation number).

3 - Dobereinerian Level of Understanding (1829 - "Law of Triads")
Understands that the periodic table is composed of groups or families of elements with similar physical properties. (May also show some understanding of chemical properties.)

2 - Davian Level of Understanding (1807 - Discovery of 5 metals)
Can identify one or more of the physical properties of the elements (metal/nonmetal, solid/liquid/gas, colors) by element.

1 - Lavoisierian Level of Understanding (1789 - "List of elements")
Can identify some of the elements represented on the periodic table. May confuse compounds with elements.

0 – Boylian Level of Understanding (1661 – “Did not know what one was”)
Shows no degree of familiarity with the periodic table; cannot name any of the elements.
APPENDIX B

PILOT STUDY REPORT

PURPOSE

The purpose of this study was to explore how selected high school chemistry students’ understanding of the elements, structure, and periodicity of the periodic table changed as they participated in four research-based activities incorporating exemplary graphics and actual household products. This study was conducted in the spring of 2001 with a class of ten junior and senior high school chemistry students at a small rural public school in the Deep South. This chemistry class was part of a block schedule, with class periods lasting 1 hour and 37 minutes. Three students were selected and agreed to be interviewed and to coconstruct concept maps with the researcher. Pseudonyms are used in the report to protect their identity. These students were all classified as juniors, and represented three different ability levels (Karen, high; Mike, medium; Leah, low). Qualitative data in the form of interviews, concept maps and student worksheets were collected for analysis. The lesson plans and the interview protocols that were used in this study have been revised, and are included in the Appendices. The Periodic Table Literacy Rubric (PTLR) was developed to identify levels of understanding of periodicity. It is also included in the Appendices.

The pilot study focused on the following activities:

1. Pretreatment interviews and coconstructing concept maps.

2. Activity #1: The Pictorial Periodic Table

3. Interviews and coconstructing concept maps.

4. Activity #2: Product Analysis I

5. Activity #3: Product Analysis II

6. Interviews and coconstructing concept maps.

7. Activity #4: Recreating the Periodic Table Mendeleyevian Style

8. Posttreatment interviews and coconstructing concept maps.

RESULTS

1. PRETREATMENT INTERVIEWS AND COCONSTRUCTING CONCEPT MAPS

The interviews and concept mapping sessions were conducted on January 18-19, 2001, at the beginning of the second semester. Students were first given a list of 13 elements (which were not identified as elements), and asked if there was any connection or relationship between them. Karen and Mike stated that they were all elements of the periodic table. Leah stated that she did not know how they were related. The students were then asked to identify anything they knew
about each of the elements in the list, especially their occurrences and uses. The chart below gives the number of elements in the sample list that students both recognized and could give some additional information (occurrence, use, physical characteristics).

### NUMBER OF ELEMENTS FROM SAMPLE LIST THAT STUDENTS COULD GIVE ADDITIONAL INFORMATION ABOUT

<table>
<thead>
<tr>
<th>Student</th>
<th># of Elements</th>
<th>% Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karen</td>
<td>11</td>
<td>85 %</td>
</tr>
<tr>
<td>Mike</td>
<td>9</td>
<td>69 %</td>
</tr>
<tr>
<td>Leah</td>
<td>2</td>
<td>15 %</td>
</tr>
</tbody>
</table>

The interview and concept maps indicate that each student came to this unit of study with either a PTLR Level 1 or 2 understanding of the periodic table. Leah, who did not identify the list of elements as such, and who only recognized two of the elements on the list, was at PTLR Level 1. She reported that the periodic table contains elements, and that each element block had an “abbreviation” and “numbers.” Leah also stated that the “elements can form circles.” She was unable to elaborate further on this statement.

Karen and Mike were both at a PTLR Level 2 of understanding. Along with Level 1 concepts, they each discussed aspects of the physical properties of the elements. Mike had a substantial understanding of the concept of metals and nonmetals, giving examples of each and reporting that they were divided by a diagonal line on the periodic table. He also reported that some metals were manmade and some were natural, with the manmade ones being located at the bottom of the table. When asked to identify any patterns on the table, Mike stated that the “elements are arranged in order by mass.” When asked to elaborate on this statement, he could not, indicating that he was only familiar with one of the prerequisite physical patterns needed to understand periodicity.

When asked about the physical properties of elements, Karen identified all three phases and metals, with no mention of nonmetals. When asked about the blocks at the bottom of the table, she reported that they were synthesized, manmade and organic. Karen had several other misconceptions along with the “organic” concept. She stated that the elements are permeable or impermeable; weightless or heavy; and that radioactive elements are colorless.

Several changes were made to the pretreatment interview and concept mapping protocol as a result of this pilot study. The periodic table that was supplied to students for this interview did not have group and series numbers. These were added to the posttreatment interview table, and will be added to the pretreatment table for the proposed study. Questions probing student knowledge of group number, series number and the zig-zag boundary line were added to the revised protocol. A section probing students’ understanding of the differences between elements and compounds will be added for the formal study. The sequence of the interview questions was also changed to reflect the progression of conceptual understanding as illustrated in the PTLR.
2. ACTIVITY #1: INTRODUCTION TO THE ELEMENTS AND THE PERIODIC TABLE

This activity was conducted during one class period, on January 22nd (the second week of school). It was designed to give students a meaningful introduction to the elements and the periodic table. The primary objective was to help students become familiar with the physical properties of the elements, and understand that everything is made of one or more elements. It began with students completing the “Chemical Survey” assessment from the SEPUP kit “Solutions and Pollution.” The purpose of the survey was to assess their understanding of the concept “chemical.” After discussing with students the fact that everything was made of chemicals, their attention was drawn to the pictorial periodic tables that were distributed to them (notebook size) and that were displayed on the classroom wall (poster size). These pictorial tables featured an actual photograph of each element in its element box. Students were told that everything (natural or manmade) is made of one or more of these elements. Students were then asked to record their observations of this pictorial table, especially any patterns that they saw. All three subjects commented on the colors of the elements in their observation notes. Karen and Leah recorded that most of the elements are silver. Karen also noted that most of the elements were solids, and that the synthetic elements were radioactive. She also identified the two liquid elements. Mike recorded that the elements were in order of number, and organized or separated by background colors.

Using these pictorial tables as a reference, students then mapped out the colors of the elements with colored markers on a blank version of the periodic table. On a separate periodic table they also mapped out the phase of each element, as portrayed on the pictorial table. These maps provided students with a visual record of the colors and phases of the elements. After students completed their periodic table maps, the various patterns related to the physical properties of the elements (color, metals vs. nonmetals, phase) were reviewed with students. The chemical property of reactivity was discussed briefly to identify why the metals of the first two groups were stored in glass containers.

Students needed very little encouragement to begin and complete activity #1. This was a very positive sign, considering that this was the afternoon class that followed lunch. In her posttreatment interview at the end of the unit, Leah reported that this was her favorite activity of the four.

For the proposed study, this activity will be extended to include instruction on the organization of the elements into groups or families. Students will label their periodic table maps with the group numbers, and use their maps to identify the common physical and chemical characteristics of the elements in each group or family. This may help some of the students immediately progress to PTLR Level 3 of understanding.

3. INTERVIEWS AND COCONSTRUCTING CONCEPT MAPS

This interview/concept mapping session was conducted on January 23rd, the day following the completion of activity #1. The interviews and concept maps of all three students indicated that they were at a PTLR Level 2 of understanding. Karen and Mike were at a Level 2 understanding prior to this activity, however, their understanding of Level 2 concepts was much more developed than that indicated during the pretreatment assessment. Leah moved from a Level 1 to a Level 2 understanding since the pretreatment assessment, however, her understanding was much more limited compared to Karen and Mike.
All three students identified the phases in which the elements exist, the two elements that exist in liquid form, and the pattern on the periodic table for the elements that are gases. Karen actually incorporated the term “phase” as a subsuming concept in her concept map. Novak (1998) defines subsuming concept as a more general concept under which more specific concepts are linked.

Karen and Mike both identified the zig-zag line as the boundary separating metals and nonmetals. On her concept map, Karen used the term “classification” as a subsuming concept for metals, metalloids, nonmetals, noble gases and radioactive elements, giving examples of each in terms of actual elements and/or their colors. Mike used correct propositions to subsume metals and nonmetals under the concept solid. Like Karen he identified numerous elements and their colors as examples in this area of his map.

Leah’s concept map indicated that her understanding of the physical properties did not extend beyond the phases. She appeared to have arbitrarily connected the following terms on her concept map: “chemicals” to “gases,” “colors” to “solids,” “elements” to “liquids.” When asked about the location of the metals Leah said they were in the middle and silver. She did not use the term nonmetal, and did not know the significance of the zig-zag line.

The protocol for interview #2 will be modified to incorporate questions about the organization of the elements on the table, particularly probing students’ knowledge about groups or families of elements. The following seed concepts were provided for the concept map construction during this session: chemicals, phases, zig-zag line. Several more will be provided during the proposed study, as is planned for the pretreatment assessment.

4. ACTIVITY #2: PRODUCT ANALYSIS I ACTIVITY

This activity was conducted over two class periods, on February 5th & 6th, and was scheduled after students had learned their element symbols and names. The objectives of this activity were the following:
* Distinguish elements from compounds.
* Identify elements and compounds in household products.
* Identify the location of elements on the periodic table.

The activity began with an introduction to the Periodic Table for Biology, which students used to analyze the nutritional benefit of various food and health products. Students were instructed to list the elements that they could identify in each product. As students began the activity, it was evident that the majority of the students had not yet mastered the concept of element, as many listed compound names along with element names on their worksheets. It was also discovered that the activity was rather confusing for students, with too many products, worksheets and instructions delivered at once. A revision was completed prior to the second day of the activity, and students responded favorably to the modifications. The original activity was divided into a sequence of shorter segments, requiring students to analyze only one product at a time.

At the beginning of the second class, the confusion students had related to elements and compounds was addressed. During the mapping exercise students were instructed to shade in the element boxes of the identified elements. This was a very time consuming process. Karen reported, “I think that the projects were informative, but boring because of their duration.” During the proposed study students will be instructed to circle the identified elements with their markers, which will greatly reduce the time required for this activity. Even with this change, the element mapping will still be visually prominent.
5. ACTIVITY #3: PRODUCT ANALYSIS II ACTIVITY

Activity #3 immediately followed activity #2, and was conducted over four class periods, on February 7th-9th, and 13th. The objectives of activity #3, like activity #2, were the following:

* Distinguish elements from compounds.
* Identify elements and compounds in household products.
* Identify the location of elements on the periodic table.

In this activity, students were given eight sets of products, with each product set representing elements from a particular group or family. Students were instructed to analyze each product in a group or family set, and identify which of the elements from the group was contained in that product. Students were asked to record the chemical compound that the element was found in, and to list other elements that were in the product.

During the posttreatment interview, students reported that this was their favorite activity of the four. Karen stated, “I was also surprised to learn that many everyday products are composed of elements that I didn’t know that they were composed of.” Students also reported that there were too many products to analyze. Activity #3 was revised to reflect this recommendation.

Activities #2 & #3 were both revised to include a similar extension activity. In this extension, students will use the information they collect from the household products to graphically display reactivity patterns among element groups. Often airlines make available to passengers a magazine containing maps which graphically display different flight paths or connections. A quick look at one of these maps allows the viewer to identify the cities that are served by a particular airline, and which of those cities are its major hubs. The proposed extension activity will similarly identify the different reaction paths or connections between elements on the periodic table. It will also be used to identify oxygen as a “hub element,” which reacts with many other different elements to form compounds. In the proposed study students will map out the elements found in compounds they identify in the household products. For each compound students will take markers and connect the blocks of the elements in that compound.

The modified versions of activities #2 & #3 should help increase student understanding of the organization and reactivity of the elements, as well as achieve the originally stated goals related to the concept of element.

6. INTERVIEWS AND COCONSTRUCTING CONCEPT MAPS.

This assessment was conducted on February 15th and 20th. Due to the similarity of activities #2 & #3, this assessment was scheduled after activity #3, when both activities were completed. Students were provided the following seed concepts for their concept maps: living things, household products and compounds. The students’ interviews and concept maps indicated that all three understood the distinction between an element and a compound. During the interview students were asked to identify the elements in a list of both elements and compounds. They were also given a product and asked to identify the elements found in it. Overall students performed very well on both these tasks.

It was also evident that they had made connections between the elements and everyday household products. The students’ gave the following element-product links as examples in their concept maps:
Karen: Selenium in Selsun Blue, fluorine in Dannon water, titanium in the battery.
Mike: Calcium in Tums, bismuth in Pepto-Bismol, chlorine in Chlorox.
Leah: Magnesium in Milk of Magnesia

As discussed above, the primary focus of activities #2 & #3 during this pilot study was to help develop students’ understanding of the concept of element. Because these activities did not focus on the organization of the elements and periodicity, the PTLR was not applied in analyzing this data. However, as discussed above, the modified versions of activities #2 & #3 will address these areas. Therefore, the protocol for the proposed study will be modified accordingly, and the PTLR will be applied in the analysis of this data.

7. ACTIVITY #4: RECONSTRUCTING THE PERIODIC TABLE

This activity was conducted over a five class periods on April 23rd-26th and 30th, the week following spring break for students. It followed the instructional unit on electron configuration. The goal of this activity was to help develop students’ understanding of the following:

* The organizational structure of the periodic table.
* Periodic patterns and trends present on the table.
* Periodicity.

In this activity student groups were given a set of element cards, with each card featuring the photograph of an element, along with the atomic number and atomic mass. Students were instructed to place the elements cards in order of increasing atomic number, and to record any patterns that they noticed. Below are some of the observations they listed:

* Atomic number increases as the atomic mass increases.
* The pattern goes solids, gases, solids, gases, etc.
* The crushed metals are grouped together.
* Divided into eight
* First one always metal
* The last two are always very reactive metals.

Students were then asked to separate and record any repeated sequences they saw. Listed below are the sequences each group recorded:

Group #1 Li,Be B-Mg Al-Ca Ga-Sr In-Ba
(groups of eight beginning with group 3)

Group #2 Li-Ne Na-Ar K-Kr
(groups of eight beginning with group 1)

Group #3: Li Be-C N-K Ca-As Se-Sn Sb-I Xe-Cs
(crushed metals are grouped together)

Group #4 Li Be-C N-Ne Na Mg-S Cl,Ar K Ca-Se Br,Kr Rb,Sr In-Te I, Xe Cs, Ba
(metals in glass, solids, gases)
Students were then guided in the construction of the main groups block of the periodic table. At this point the structure of the periodic table and the concept of periodicity was explained to students at length using the analogy of the weekly periods of days on the calendar. Students were then guided in the addition of the “d” and “f” sublevel blocks into their periodic table. The connection between electron configuration and the structure and periodicity of the periodic table was discussed in great detail with students. Students then completed a worksheet identifying the physical and chemical properties of each element group. This was later reviewed with students, emphasizing the periodic patterns associated with all of these properties.

Lastly, students completed a chart identifying the periodic trends for atomic size, ionization energy, electron affinity, electronegativity, reactivity of metals and reactivity of nonmetals. Students were shown a short video illustrating the reactivity of the alkali metals to help them understand the reactivity of metals and nonmetals within groups. They used the visual periodic tables in their textbooks to complete the other listed trends.

8. POSTTREATMENT INTERVIEWS AND COCONSTRUCTING CONCEPT MAPS.

The final assessment of the pilot study occurred on May 1st, 7th and 10th. The range in dates was due to schedule conflicts and one student’s illness. The students were provided the following seed concepts for their concept maps: organization, properties and periodicity. At the conclusion of the final interview, students were given the element cards and asked to recreate the periodic table in its expanded form (with the “f” series inserted in the body of the table).

The data from this final assessment indicated that each of the three students was at a different level of understanding of the periodic table at the conclusion of this pilot study. However, the knowledge structures of Karen and Mike were very similar. Their concept maps and interviews indicated that they both had a substantial understanding of the following:

* The physical properties of the elements (phase, metal/nonmetal, colors)
* The relationship between metals/nonmetals and the phases of elements.
* The structure of the periodic table in terms of groups, periods & sublevel blocks.
* Group characteristics (# of outer shell electrons, outermost sublevel, variations of reactivity within a group - Mike, oxidation number - Karen).

The concept maps of both students had good detail and correct propositions. No misconceptions were detected. The most substantial difference between the two students was their understanding of periodicity. Karen, when asked to explain periodicity, stated, “Elements are grouped by their atomic number, which reveals their chemical and physical properties.” When asked how the element card activity worked she stated that the cards were, “In order by atomic number, then separated by eights, then groups fell in the correct columns and rows.” When Karen reconstructed the periodic table during the interview, she followed the same procedure she gave above. The data indicate that she did understand the concept of periodicity, and had reached PTLR Level 5.

Mike seemed to have not yet reached an understanding of periodicity. When he was asked to explain periodicity during the interview, he had no response. Mike did, however, include the following proposition on his concept map: “The periodic table consists of elements
which has an organization of series, are laid out by increasing atomic number.” This statement indicated a partial understanding of periodicity. When Mike recreated the periodic table during the interview, he did so by reconstructing the individual groups, without placing the elements in order of atomic number first. The data seem to indicate that Mike had reached Level 4 of the PTLR. He had a very firm grasp of the characteristic properties of the groups, and the structure of the table, but he had not quite understood the basis for these patterns.

Leah appears to have progressed only to a Level 2 on the PTLR. Her interview responses and concept map indicate that she could identify the physical properties of the elements (metal, nonmetal, phases). They also indicate she had only become familiar with the terminology related to the organization of the periodic table (groups, periods, sublevels). She demonstrated no real understanding of the meaning of these terms, particularly the basis for the groups of the periodic table. Leah was able to reconstruct the table with the element cards, however, based on the way she constructed it, (period on top of period) it only indicates that she was familiar with the shape or form of the table.

Leah’s interview and concept map also indicate that she left this unit study with a number of misconceptions. One of the most prominent ones relates to the relationship between phase and electron configuration. Leah seemed to arbitrarily connect the individual phases (solid, liquid, gas, noble gas) with the individual sublevels (s, p, d, f) on her map. This had also occurred on her map in the second assessment session. Other misconceptions included:
* The phases are solid, liquid, gas and noble gas.
* Solids are metals
* The “p” sublevel block in on the left of the table, the “s” is on the right.
* The “f” sublevel block contains noble gases.
* The zig-zag line separates liquids from solids.

As stated above, all three students correctly assembled the element cards into the main group elements section of the table. They were also asked to construct the expanded form of the table, with the “f” series incorporated into the body of the table. They all three failed to completely and correctly incorporate both the “d” and “f” sublevel blocks into their table.

CONCLUSIONS

This pilot study greatly enhanced and improved the proposed activities, data collection and data analysis components of the proposed doctoral research study. This researcher will enter the formal study with many tentative conclusions derived from this study. The chart below indicates the progress that each student made across the study.

### STUDENTS’ PTLR LEVEL OF UNDERSTANDING

<table>
<thead>
<tr>
<th>Student</th>
<th>Initial Interview</th>
<th>After Activity 1</th>
<th>Final Interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karen</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Mike</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Leah</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
The results of the study show that Karen and Mike made significant gains in their understanding of periodicity through the four activities. Karen (high ability) moved up 3 levels of literacy, to end with a Level 5 understanding. Mike (medium ability) moved up 2 levels and ended at Level 4. Leah (low ability), however, moved up only 1 level to end at Level 2.

Why did Karen and Mike make so much greater progress? One factor would appear to be the degree of familiarity that these students had with the elements themselves, and their properties, particularly their physical properties. During the pretreatment interview at the beginning of the study, students Karen and Mike identified and gave additional information for the majority of the 13 elements they were presented (Karen - 11 elements, Mike - 9 elements). Leah, conversely, identified and gave additional information for only 2 of the 13 elements. During this same interview, Karen and Mike identified some of the physical properties of the elements (phases, metal, nonmetal), while Leah could give none. It seems that Leah started with a very limited understanding of the elements and no knowledge of their physical properties, and this lack of prior knowledge seemed to hinder her progress throughout the study. It appears that students need to have some degree of familiarity with the elements, some meaningful connections to them, and an understanding of their basic physical properties before they can begin to “see” the patterns present on the periodic table.

A careful analysis of Mike’s data at the end of the study reveals that he had all the prerequisite knowledge to understand the concept of periodicity at Level 5, yet he did not. This seems to be tentative evidence of a critical juncture between Level 4 and Level 5 on the PTLR. A critical juncture in this context is a point in which students must put all the pieces together to see the big picture of periodicity, as Mendeleyev did in 1869. The ending status of Mike seems to indicate that students can know quite a lot about the periodic patterns on the table, and still not understand periodicity.

The pictorial periodic table used in activities #1 & #4 seemed to particularly help students visualize the periodic patterns represented on the table. Activity #1 helped all three students increase their knowledge of the physical properties of the elements, and the patterns of these properties on the periodic table. It appears students should be well grounded in this knowledge before they can understand the concept of a group or family of elements having similar physical and chemical properties. The visual presentation of these physical properties (solid, liquid, gas, metal, nonmetal, color) provided a very concrete and meaningful experience for students. Given the much more abstract nature of the chemical properties (oxidation number, electron configuration, reactivity), it would seem all the more important to help students gain a firm understanding of the physical properties of the elements.

Activity #2 and activity #3 apparently provided very meaningful experiences for students to become increasingly familiar with the elements, as evidenced by their comments in the final interview. All three students reported either activity #2 or #3 as their favorite activity of the four they participated in. In reference to activity #3, Karen reported it was “amazing to find out the elements that show (up) over and over.” Also in reference to activity #3, Mike stated that the “products had most of the elements on the periodic table.” Leah reported that activity #2, was her personal favorite. “You learned what was good for your system (body), and what was not good.”

In both of these activities, students had to identify elements in common household products (cereal, multimineral supplements, salt, etc.). Prior to this activity, students were required to learn the names and symbols of approximately 40 elements. Students initially had difficulty with the task of distinguishing elements from compounds as they analyzed the product
labels. However, as they progressed through these activities they appeared to become proficient. In the interview session following these two activities, all three students were able to distinguish elements from compounds in a list and from the label of a product container.

Activity #4 appeared to have great utility in helping students learn about the structure of the periodic table. In this activity students reconstructed the periodic table with a set of element cards, which were created from the same types of pictorial periodic tables that were used in activity #1. Student worked in pairs during this activity, and recorded the patterns they saw as they reconstructed the table. Their activity sheets revealed that individual students saw different patterns in the cards. What they all had in common was their use of the physical and chemical properties of the elements (phase, metal vs nonmetal, color, atomic mass and atomic number) in their description of the patterns they saw. Also, when students were asked to recreate the table with the cards during the posttreatment interview, each of the three students followed a slightly different procedure in their recreation, indicating that they remembered the structure or form of the table somewhat differently. This appears to correspond with Solso’s (1990) theory of visual cognition, which states that our prior knowledge affects what and how we see. The results above also seem to support what the literature suggests, that periodicity is a difficult concept to understand, even when meaningful, concrete learning experiences are provided.

During activity #4, students had only one opportunity to recreate the table with the cards. Mike and Leah might have been able to advance to higher Levels of the PTLR if they had been provided with additional experiences with the element cards. During the formal study, students will be provided at least three occasions to reconstruct the table.

As anticipated, the qualitative data collection methods of interviewing and concept mapping were very effective in revealing how students’ understanding changed incrementally through the activities of the pilot study. Student worksheets from the activities also proved to be a valuable source of data. As discussed throughout the results section, a number of changes will be made to the interview protocols before the proposed study. In some cases questions will be added to target areas missed during the pilot study, and in other cases questions will be revised or reordered to improve the quality of data obtained.

Students participating in this study had no prior experience with concept mapping. Trowbridge (1995) had to drop the pretreatment concept mapping phase from his study, due to frustration on the part of student subjects. No such frustration was noted during this study. The participating students tolerated very well the 45 to 60 minute interview/concept mapping sessions. The interviews typically lasted 10-15 minutes, with the concept map coconstruction sessions lasting 30-40 minutes. The length of these sessions was partly due to the fact that the number of seed concepts provided to students was few to none, and the fact that students were unfamiliar with the technique. In the proposed study students will be taught, and will practice concept mapping prior to the pretreatment data collection. Also, a number of seed concepts will be provided to them for possible use in their maps. This should shorten the duration of the concept mapping sessions, and possibly increase the quality of the maps.
APPENDIX C

INTERVIEW PROTOCOLS

PROTOCOL FOR INTERVIEW ONE

Introductions/Purpose of Interview

ACADEMIC & CAREER INTEREST OF STUDENT
What subjects do you enjoy studying in school? What do you want to do after you finish high school?

ELEMENT
What is an element? How many are there?

Are there differences between elements? What are they?

ELEMENT VS COMPOUND
Present students with a list of elements and compounds.
Circle any elements that you see in this list.

What are the ones that aren’t elements?

What is the difference between an element and a compound?

PERIODIC TABLE - GENERAL
Give students a plain version of the periodic table, with the group & period numbers included.

What do you know about this graphic?

Have you studied this before? When and what did you learn about it? Did you have to learn the symbols?

Are there any patterns represented on the periodic table?

ELEMENT BLOCKS
What is the purpose of each of the little blocks?

What information is included in each block?

PHYSICAL PROPERTIES
What are some of the physical properties of the elements?

Are there any patterns on the table related to the physical properties of the elements? What are they?
Can you mark the location of the zig-zag line on this PT? What is its purpose?

**CHEMICAL PROPERTIES**
What are some of the chemical properties of the elements?

Are there any patterns on the table related to the chemical properties of the elements? What are they?

**ORGANIZATIONAL STRUCTURE**
Can you explain why it is shaped the way it is?

What are some of the different ways that elements are grouped, organized or classified on the periodic table?

What is the basis of these groupings, organization or classification, or how did they come to be grouped this way?

Why are these numbers placed across the top here?
  What is a group/family?
  How are these elements alike and/or different?

Why are these numbers placed down the left side of the table?
  What is a series/period?
  How are these elements alike and/or different?

Why are these blocks (f series) located at the bottom?

**PERIODICITY**
What is periodicity?

**USE/IMPORTANCE**
Have you used this graphic before?

Why is this graphic important to the study of chemistry?
CONCEPT MAP CONSTRUCTION

1. I am now going to help you construct a concept map of what you know about the periodic table. We are going to use a program on the computer to help us do this. Notice that the periodic table is in a box at the top of the screen, and that I have given you some concepts to start with. You may use some or all of them. 
*The following concepts are displayed on the computer screen: elements, element block, organization, physical properties, chemical properties, patterns, periodicity.*

2. Name any other terms, words, concepts that you associate with the periodic table of the elements. As you state them, I will add them on the computer screen.

3. What are several of the most general or important terms/words/concepts that you have listed, under which all of the rest of the terms can be organized? As you state them I am going to move them below the periodic table box, and connect each one to it with a linking line.

4. Please think of one or more linking words that we can place on each linking line that describes the relationship between the periodic table and the concept. As we look at the link from the periodic table down to the next concept, we want it to read like a phrase or a sentence.

5. Now try to link the remainder of the concepts under this first row of concepts in a similar way. You may have several layers of concepts under each of the concepts in the first row. Try to provide one or more linking words for each connection.

6. At any point in this process you can change any part of your map. You may add any other words/terms/concepts that you have thought of while we are doing this. You may also move a concept from one point on the map to another point.

7. Look for any way that you can link concepts across the map, as well as down the map.
INTERVIEW #1 - Circle any elements that you see in this list.

water
potassium iodide
helium
calcium carbonate
salt
titanium dioxide
carbohydrate
sulfur
trisodium phosphate
riboflavin
chromium chloride
copper
thiamin mononitrate
magnesium
sodium fluoride
zinc oxide
PROTOCOL FOR INTERVIEW TWO

Provide students with a plain version of the periodic table.

PERIODIC TABLE
What have you learned about the PT since the last interview?

Did you discover any patterns of the elements on the periodic table? What are they?

PHYSICAL PROPERTIES
What are some of the physical properties of the elements?

Are there any patterns of physical properties of the elements on the periodic table?

Can you mark the location of the zig-zag line on this PT? What was its purpose?
   Where do we find metals? Nonmetals?
   Where can we find solid, liquids and gases on the periodic table? Can you mark their location?

What are some of the patterns related to the colors of the elements?

What is the relationship between metals/nonmetals and solids/liquids/gases?

CHEMICAL PROPERTIES
What are some of the chemical properties of the elements?

Are there any patterns on the table related to the chemical properties of the elements? What are they?

ORGANIZATIONAL STRUCTURE
How are the elements are grouped, organized or classified on the periodic table?

What is the basis of these groupings, organization or classification?

Why are these numbers placed across the top here?
   What is a group/family?
   How are these elements alike and/or different?

Did you like this activity? What did you like about it?

Is there anything else you can tell me that you learned about the PT?
PROTOCOL FOR INTERVIEW THREE

GENERAL
What did you learn about the elements and the periodic table from the activities since the last interview? (I.e. From the analysis of food & nutrition products using the periodic table of the elements for biology)

What did you learn from the analysis of ingredient labels of the products?

What did you learn from the periodic table mapping of the 3 products using the PT of biology?

What did you learn from the compound mapping activity?

THE ELEMENTS AND BIOLOGY
What were the different nutrition related categories of elements on the Periodic Table of the Elements for Biology?

Provide for the student a blank copy of the periodic table, and the color codes for the categories he/she identified.

Can you mark on this periodic table any patterns related to the groupings of elements that belong to each category?

Which elements are the most important nutrients, and needed in the largest quantity in the body? Why?

Which elements are the next most important nutrients, and needed in much smaller quantities in the body? Why?

Which elements are harmful to our body, and are not needed in any quantity? Why?

Describe the relative nutritional value of the three products that you analyzed.

ELEMENTS AND COMPOUNDS
Provide for the student a food or nutritional product container.
Identify all of the elements in the following product.

What is the difference between an element and a compound?

CHEMICAL PROPERTIES
Are there any patterns on the table related to the reactivity of the elements?

Are there types of elements that tend to combine together to form compounds? What types of compounds are formed as a result?
Are there specific groups or families of elements that tend to combine together to form compounds? What types of compounds are formed as a result?

Which element tends to combine individually with many other different elements to form compounds?

What types of compounds does this element form?

**ORGANIZATIONAL STRUCTURE**

Did you learn anything about how the elements are grouped, organized or classified on the periodic table during this exercise?

Is there anything else you can tell me that you learned about the PT?

Did you like this activity? What did you like about it?

Did you like the PT of Biology, and did it help you learn about the elements and the PT?
PROTOCOL FOR INTERVIEW FOUR

GENERAL
What did you learn about the elements and the periodic table when you analyzed the household products?

What were some of the products, and the elements you found in those products?

What did you learn about the elements and the periodic table when you did the compound mapping?

What were your top three most interesting finds during this activity?

CHEMICAL PROPERTIES
What is reactivity? Which elements are reactive?

Are there any patterns on the table related to the reactivity of the elements?

Are there types of elements that tend to combine together to form compounds? What types of compounds are formed as a result?

Are there specific groups or families of elements that tend to combine together to form compounds? What types of compounds are formed as a result?

Which five elements appeared most frequently in the products? Why?

Which single element appeared most frequently, and tended to combine individually with many other different elements to form compounds? Why?

What types of compounds does this element form?

ORGANIZATIONAL STRUCTURE
What are some of the different ways that elements are grouped, organized or classified on the periodic table? Why?

What do the elements in a group or family have in common?

Is there anything else you can tell me that you learned about the PT?

Did you like this activity? What did you like about it?
PROTOCOL FOR INTERVIEW FIVE

PERIODIC TABLE - GENERAL
Give students a plain version of the periodic table, with the group & period numbers included.

PHYSICAL PROPERTIES
What are some of the physical properties of the elements?

Are there any patterns on the table related to the physical properties of the elements? What are they?

What is atomic size?

Are there any patterns on the table related to the atomic size of the elements? What are they?

CHEMICAL PROPERTIES
What are some of the chemical properties of the elements?

What is reactivity?

Are there any patterns on the PT related to reactivity? What are they?

What is oxidation number?

Are there any patterns on the PT related to oxidation number? What are they?

What is electron configuration?

Are there any patterns on the PT related to EC? What are they?

ORGANIZATIONAL STRUCTURE
What are some of the different ways that elements are grouped, organized or classified on the periodic table? Why?

Can you explain why it is shaped the way it is?

Why are these numbers placed across the top here?
   What is a group/family of elements?
   What do they have in common?
   How do they differ?

Why are these numbers placed down the left side of the table?
   What is a series/period of elements?
   What do they have in common?
   How do they differ?
Why are these blocks (f series) located at the bottom?

**PERIODICITY**
What is the organizational basis of the periodic table?

What is periodicity?

**USE/IMPORTANCE**
Is there anything else you can tell me that you learned about the PT?

Did you like this activity? What did you like about it?

Which instructional activity did you like the best? Why?

In which instructional activity do you think you learned the most about the periodic table and the elements? Why?

Did you like the PT of pictures? Was it helpful in learning about the PT?

**PERIODIC TABLE RECONSTRUCTION ACTIVITY**
*Provide the student with a set of element cards.*

Take the set of element cards and reconstruct the periodic table in the expanded form. As you reconstruct the table, tell me what you are doing at each step along the way.
APPENDIX D

COCONSTRUCTED CONCEPT MAPS
Figure D1. Interview One Concept Map of S1.
Figure D2. Interview One Concept Map of S2.
Figure D3. Interview One Concept Map of S3.
Figure D4. Interview One Concept Map of S4.
Figure D5. Interview One Concept Map of S5.
Figure D6. Interview One Concept Map of S6.
Figure D7. Interview Two Concept Map for S1.
Figure D8. Interview Two Concept Map of S2.
Figure D9. Interview Two Concept Map of S3.
Figure D10. Interview Two Concept Map of S4.
Figure D11. Interview Two Concept Map of S5.
Figure D12. Interview Two Concept Map of S6.
Figure D13. Interview Three Concept Map of S1.
Figure D14. Interview Three Concept Map of S2.
Figure D15. Interview Three Concept Map of S3.
Figure D16. Interview Three Concept Map of S4.
Figure D17. Interview Three Concept Map of S5.
Figure D18. Interview Three Concept Map of S6.
Figure D19. Interview Four Concept Map of S1.
Figure D20. Interview Four Concept Map of S2.
Figure D21. Interview Four Concept Map of S3.
Figure D22. Interview Four Concept Map of S4.
Figure D23. Interview Four Concept Map of S5.
Figure D24. Interview Four Concept Map of S6.
Figure D25. Interview Five Concept Map of S1.

Seed concepts provided and not used in the map: PATTERNS.
Figure D26. Interview Five Concept Map of S2.
Figure D27. Interview Five Concept Map of S3.
Figure D28. Interview Five Concept Map of S4.
Seed concepts provided and not used in the map: PATTERNS.

Figure D29. Interview Five Concept Map of S5.
Figure D30. Interview Five Concept Map of S6.
Figure D31. Concept Map of CS1.
Figure D32. Concept Map of CS2.
Figure D33. Concept Map of CS3.
Figure D34. Concept Map of CS4.
Figure D35. Concept Map of CS5.
Figure D36. Concept Map of CS6.
# Element Identification Chart

<table>
<thead>
<tr>
<th>Element # or Form</th>
<th>Color</th>
<th>Phase</th>
<th>Metal/Nonmetal</th>
<th>Element Prediction (Symbol)</th>
<th>Actual Element (Symbol)</th>
<th>Actual Element (Name)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element #1</td>
<td>Colorless</td>
<td>Gas</td>
<td>Nonmetal</td>
<td>Ar</td>
<td>Ar</td>
<td>Argon</td>
</tr>
<tr>
<td>Element #2</td>
<td>Colorless</td>
<td>Gas</td>
<td>Nonmetal</td>
<td>O</td>
<td>O</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Element #3</td>
<td>Colorless</td>
<td>Gas</td>
<td>Nonmetal</td>
<td>N</td>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Element #4</td>
<td>Black</td>
<td>Solid</td>
<td>Metal</td>
<td>Pb</td>
<td>C</td>
<td>Carbon</td>
</tr>
<tr>
<td>Element #5</td>
<td>Yellow</td>
<td>Powdered</td>
<td>Non-metal</td>
<td>S</td>
<td>S</td>
<td>Sulfur</td>
</tr>
<tr>
<td>Element #6</td>
<td>Brown</td>
<td>Liquid</td>
<td>Nonmetal</td>
<td>I</td>
<td>I</td>
<td>Indium</td>
</tr>
<tr>
<td>Foil</td>
<td>Silver</td>
<td>Solid</td>
<td>Nonmetal</td>
<td>Al</td>
<td>Al</td>
<td>Aluminium</td>
</tr>
<tr>
<td>Bolt or Nut</td>
<td>Silver</td>
<td>Solid</td>
<td>Metal</td>
<td>Fe</td>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>Coin</td>
<td>Brown</td>
<td>Solid</td>
<td>Metal</td>
<td>Cu</td>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>Paper clip</td>
<td>Silver</td>
<td>Solid</td>
<td>Metal</td>
<td>Fe</td>
<td>Zn</td>
<td>Zinc</td>
</tr>
<tr>
<td>Shot</td>
<td>Blaiz gray</td>
<td>Solid</td>
<td>Metal</td>
<td>Zn</td>
<td>Pb</td>
<td>Lead</td>
</tr>
</tbody>
</table>

Phase - solid, liquid or gas.
PICTORIAL PT ACTIVITY SHEET

Name: ____________________________

1. Examine the photographs of the elements on the pictorial periodic table. Record your observations, especially any patterns you see, in the space below.

Mostly all the elements are silver. Most are metals.

The noble gases are in brown blocks.

There are not many liquids. The gases have a cylinder and the pressure circle. All the different groups have different background colors.

2. Using a blank version of the table, circle the symbols of the elements that are gases with a yellow marker, and the symbols of the elements that are liquids with a blue marker. The uncolored blocks will represent the elements that are solids. Title this periodic table "Phases of the Elements," and draw a key under the title.

3. Using your set of colored markers and your other plain version of the periodic table, circle each element's symbol with its corresponding color. Be sure to use the color of the element as it appears in the photograph, and not the background color of the element block. Use the colors of carbon (symbol C, atomic number 6) and iodine (symbol I, atomic number 53) that are illustrated on the large pictorial periodic table displayed on the classroom wall. Leave the elements in the column on the far right (He, Ne, Ar, Kr, Xe, Rn) uncolored. Place a red "x" through the blocks of elements that are radioactive. Title this periodic table "Colors of the Elements."

4. Draw the zig-zag line displayed on the large classroom pictorial periodic table onto your periodic tables.
Periodic Table of the Elements

Colors of the Elements

Very active
Active
Alkaline Earth Metals
Non-active
Noble Gases

He

1

H

2

Li Be

Be

Na Mg

K Ca

Sc Ti V Cr Mn Fe Co Ni Cu Zn

Ga Ge As Se Br Kr

Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe

Cs Ba La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

Fr Ra Ac Th Pa U Np Pu Am Cm Bk Cf Es Ac Rf Pm

Strontium

Calcium

Barium

Lanthanum

Cerium

Praseodymium

Neodymium

Promethium

Samarium

Europium

Gadolinium

Terbium

Holmium

Erbium

Thulium

Ytterbium

Lutetium

The periodic table is color-coded to represent the different groups of elements.
Periodic Table of the Elements
PRODUCT ANALYSIS ACTIVITY SHEET

Product: Sunrite

List each element you found in the product, along with its symbol, and the chemical compound it is found in (if identified).

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Chemical Compound or Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>calcium carbonate</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>ferric fumarate</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>aluminium phosphate</td>
</tr>
<tr>
<td>Iodine</td>
<td>I</td>
<td>potassium iodide</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>magnesium oxide</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>zinc oxide</td>
</tr>
<tr>
<td>Selenium</td>
<td>Se</td>
<td>sodium selenate</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>cupric oxide</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>magnesium sulphate</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr</td>
<td>chromium chloride</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>sodium molybdate</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>chloride</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>potassium chloride</td>
</tr>
<tr>
<td>Rubidium</td>
<td>Rb</td>
<td>sodium rubidate</td>
</tr>
<tr>
<td>Silicon</td>
<td>Si</td>
<td>sodium meta-stibide</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni</td>
<td>nickel sulfate</td>
</tr>
</tbody>
</table>
### Periodic Table of the Elements

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>He</td>
</tr>
<tr>
<td>Li</td>
<td>Be</td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
</tr>
<tr>
<td>K</td>
<td>Ca</td>
</tr>
<tr>
<td>Rb</td>
<td>Sr</td>
</tr>
<tr>
<td>Cs</td>
<td>Ba</td>
</tr>
<tr>
<td>Fr</td>
<td>Ra</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc</td>
</tr>
<tr>
<td>V</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Co</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Ga</td>
</tr>
<tr>
<td>As</td>
</tr>
<tr>
<td>Br</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
</tr>
<tr>
<td>Nb</td>
</tr>
<tr>
<td>Tc</td>
</tr>
<tr>
<td>Rh</td>
</tr>
<tr>
<td>Ag</td>
</tr>
<tr>
<td>In</td>
</tr>
<tr>
<td>Sb</td>
</tr>
<tr>
<td>I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>La</td>
</tr>
<tr>
<td>Ta</td>
</tr>
<tr>
<td>Re</td>
</tr>
<tr>
<td>Ir</td>
</tr>
<tr>
<td>Au</td>
</tr>
<tr>
<td>Tl</td>
</tr>
<tr>
<td>Bi</td>
</tr>
<tr>
<td>At</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ce</td>
</tr>
<tr>
<td>Nd</td>
</tr>
<tr>
<td>Sm</td>
</tr>
<tr>
<td>Gd</td>
</tr>
<tr>
<td>Dy</td>
</tr>
<tr>
<td>Er</td>
</tr>
<tr>
<td>Yb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th</td>
</tr>
<tr>
<td>U</td>
</tr>
<tr>
<td>Pu</td>
</tr>
<tr>
<td>Cm</td>
</tr>
<tr>
<td>Cf</td>
</tr>
<tr>
<td>Fm</td>
</tr>
<tr>
<td>No</td>
</tr>
</tbody>
</table>

**Notes:**

- **Basic Nutrients:** H, O, N, C, P
- **Macronutrients:** C, N, O, H
- **Micronutrients:** Fe, Cu, Zn
- **Trace Nutrients:** I, Br, Se
- **Rare Elements:** Tl, Pb, Bi
- **Radioactive Elements:** Th, Pa, U, Np
The compounds listed below are in the multiminer.al supplement that you analyzed. In the list below, identify the metals by circling them with a grey marker, and the nonmetals by circling them with a blue marker. Draw the zig-zag line on the periodic table to assist you in distinguishing metals from nonmetals.

- Magnesium Oxide
- Zinc Oxide
- Chromium Chloride
- Potassium Chloride
- Potassium Iodide

List below any patterns you notice.

The metals are in front of the nonmetals. Metals are combine with the nonmetals. The metals are on the left and the nonmetals are on the right.
<table>
<thead>
<tr>
<th>Period</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H (1)</td>
</tr>
<tr>
<td>2</td>
<td>Li (3), Be (4), Na (11), K (19), Rb (37), Cs (55), Fr (87)</td>
</tr>
<tr>
<td>3</td>
<td>Mg (12), Al (13), Si (14), P (15), S (16), Cl (17), Ar (18), Kr (36)</td>
</tr>
<tr>
<td>4</td>
<td>C (6), O (8), N (7), F (9), Ne (10), Mg (12), Ca (20), Sr (38), Ba (56)</td>
</tr>
<tr>
<td>5</td>
<td>Ne (10), Mg (12), Al (13), Si (14), P (15), S (16), Cl (17), Ar (18), Kr (36)</td>
</tr>
<tr>
<td>6</td>
<td>Mn (25), Fe (26), Co (27), Ni (28), Cu (29), Zn (30), Ga (31), Ge (32), As (33)</td>
</tr>
<tr>
<td>7</td>
<td>Ga (31), Ge (32), As (33), Se (34), Br (35), Kr (36), Rn (86)</td>
</tr>
</tbody>
</table>

The image shows a periodic table with some elements highlighted and connected by lines, indicating electron transitions or chemical reactions. The highlighted elements are B (5), C (6), N (7), O (8), F (9), Ne (10), Mg (12), Al (13), Si (14), P (15), S (16), Cl (17), Ar (18), and Kr (36).
<table>
<thead>
<tr>
<th>PRODUCT ANALYSIS II ACTIVITY SHEET</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT</td>
</tr>
<tr>
<td>GROUP 1 ELEMENTS</td>
</tr>
<tr>
<td>HYDROGEN</td>
</tr>
<tr>
<td>Hydrogen Peroxide</td>
</tr>
<tr>
<td>Water, $H_2O$</td>
</tr>
<tr>
<td>Other elements</td>
</tr>
<tr>
<td>Lithium</td>
</tr>
<tr>
<td>Batteries</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Salts, sodium chloride</td>
</tr>
<tr>
<td>Other elements</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
<tr>
<td>Magnesium</td>
</tr>
<tr>
<td>Magnesium Sulphate</td>
</tr>
<tr>
<td>Sulphuric acid, magnesium hydroxide</td>
</tr>
<tr>
<td>Calcium</td>
</tr>
<tr>
<td>Milk</td>
</tr>
<tr>
<td>Other elements</td>
</tr>
</tbody>
</table>

| Magnesium                         |
| Magnesium Sulphate                |
| Sulphuric acid, magnesium hydroxide|
| Calcium                           |
| Milk                              |
| Other elements                    |
PRODUCT ANALYSIS II FOLLOWUP ACTIVITY SHEET

1. Identify the seven products whose names contain part of an element name.
   Hydrogen Peroxide (H₂O₂), Ammonia (NH₃), Magnesium (Mg), Calcium (Ca), Sodium (Na), Potassium (K), Iodine (I₂)

2. Chemically speaking, what is the difference between the three different types of salt.
   Metal carbonate, metal chloride, metal nitrate.

3. How many different sodium compounds are in Dove soap? 10

4. Scan the “Other Elements” column of your worksheet and identify and rank the five elements that appeared most frequently in your analysis. Write the number of times the element appeared next to the element in the list.
   1. Oxygen 28
   2. Hydrogen 20
   3. Sodium 14
   4. Carbon 9
   5. Chlorine 7

5. Explain why these elements appear so frequently in compounds?
   These elements appear so frequently because they are used in everyday life.
ACTIVITY 4 WORKSHEET

1. Record any patterns that you see in your sequence.
   
   Greens are in pairs, yellow are in fours. After every seventh element there is a noble gas. Almost every green element is in a ________________

2. Draw slash marks in the sequence below to identify any pattern you found.

   Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Ga Ge As Se Br Kr Rb Sr In Sn Sb Te I Xe Cs Ba
   
   Metal | Metal | Gas | Metal | Nonmetal | Metal | Nonmetal | Gas | Metal | Nonmetal
   
   Li | Be | B | C | N | O | F | Ne | Na | Mg | Al | Si | P | S | Cl | Ar | K | Ca | Ga | Ge | As | Se | Br | Kr | Rb | Sr | In | Sn | Sb | Te | I | Xe | Cs | Ba
   
   3. After arranging your cards sets one over another, record your arrangement below using the elements symbols listed above.

   Periodicity - When the elements are placed are placed in order of increasing atomic number, a pattern of repeating sequences (period or series) appear revealing groups or families of elements with similar physical and chemical properties.
## Characteristics of Individual Groups or Families on the Periodic Table

<table>
<thead>
<tr>
<th>Group # &amp; Family name(s)</th>
<th>Physical characteristics (color, metal/nonmetal, solid/liquid/gas)</th>
<th>Chemical characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1 - A: Metal</strong></td>
<td>Mostly silver, metal, solid</td>
<td>Highly reactive</td>
</tr>
<tr>
<td><strong>Group 2 - B: Earth Metal</strong></td>
<td>Mostly silver, metal, solid</td>
<td>Reactive</td>
</tr>
<tr>
<td><strong>Group 3</strong></td>
<td>Mostly silver, metal, solid</td>
<td>Inert</td>
</tr>
<tr>
<td><strong>Group 4</strong></td>
<td>Metal and nonmetal, solid</td>
<td>Inert</td>
</tr>
<tr>
<td><strong>Group 5</strong></td>
<td>Metal and nonmetal, solid, liquid, gas, colored</td>
<td>Inert</td>
</tr>
<tr>
<td><strong>Group 6</strong></td>
<td>Mostly nonmetal, colored and colorless and solid and gas</td>
<td>Reactive</td>
</tr>
<tr>
<td><strong>Group 7 - Halogen</strong></td>
<td>Mostly colored, nonmetal, solid/liquid/gas</td>
<td>Highly reactive</td>
</tr>
<tr>
<td><strong>Group 8 - Noble gases</strong></td>
<td>Colorless, nonmetallic gas</td>
<td>Inert</td>
</tr>
</tbody>
</table>
APPENDIX F

PRE- AND POSTTEST

Test Directions

Use the periodic table to help you answer the following questions. Take as much time as you need and place your answers to all the questions on the answer sheet provided. Please do not write on the question sheet.

Directions: For the multiple choice items, place the letter of the correct answer on the answer sheet. For the other items write the answer.

1. Select the symbol of the element that is the best conductor of electricity.
   a. $^{34}$Se   b. $^{20}$Ca   c. $^{7}$N   d. $^{35}$Br

2. Which of the following represents a correct chemical formula?
   a. SrBr   b. Sr$_2$Br   c. SrBr$_2$   d. Sr$_2$Br$_3$

3. Write the symbol of an element that has similar chemical properties as C.

4. Find the symbol of an element that very seldom reacts chemically. Write the symbol.

5. Find a metal in the period containing Mg that reacts faster than Mg. Write the symbol.

6. If Cl gains 1 electron, the electron configuration is:
   a. 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^5$
   b. 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^4$
   c. 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^5$ 4s$^1$
   d. 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^6$

7. Find the element that has a total of 6 electrons in its atoms. Write the symbol of the element.
8. Select the element that places its last electron in a d subshell.
   a. $^{12}_{\text{Mg}}$  b. $^{30}_{\text{Zn}}$  c. $^{36}_{\text{Kr}}$  d. $^{92}_{\text{U}}$

9. Select the most reactive atom.
   a. $^8_{\text{O}}$  b. $^{16}_{\text{S}}$  c. $^{34}_{\text{Se}}$  d. $^{52}_{\text{Te}}$

10. Find and write the symbol of an element that reacts with Ca in a 1 to 1 ratio.

11. Find an element in the family with Br that reacts slower than Br. Write the symbol.

12. Select the atom that most likely gains an additional electron?
   a. $^3_{\text{Li}}$  b. $^9_{\text{F}}$  c. $^{86}_{\text{Rn}}$  d. $^{87}_{\text{Fr}}$

13. Find the symbol of an element that reacts with Al. Write the symbol.

14. Write the electron configuration for K.

15. Atoms of the element technetium, Tc, have:
   a. 43 protons, 97 electrons  
   b. 43 protons, 54 electrons  
   c. 43 protons, 43 electrons  
   d. 97 protons, 97 electrons

16. Select the most reactive atom.
   a. $^3_{\text{Li}}$  b. $^{11}_{\text{Na}}$  c. $^{19}_{\text{K}}$  d. $^{37}_{\text{Rb}}$

17. Which of the following atoms is least reactive?
   a. $^{11}_{\text{Na}}$  b. $^9_{\text{F}}$  c. $^{87}_{\text{Fr}}$  d. $^{86}_{\text{Rn}}$

18. Give the symbol of an element that places its last electron in a s subshell and fills the subshell.

19. Find the symbol of a metal that is more reactive than Ra. Write the symbol.
20. Select the pair of atoms which are least similar in their properties.
   a. $^{17}$Cl and $^{18}$Ar  b. $^{17}$Cl and $^{9}$F  c. $^{17}$Cl and $^{53}$I  d. $^{17}$Cl and $^{35}$Br

21. If an atom of Na loses 1 electron, the electron configuration is:
   a. $1s^2 \ 2s^2 \ 2p^6 \ 3s^2$  b. $1s^2 \ 2s^2 \ 2p^6 \ 2d^1$
   c. $1s^2 \ 2s^2 \ 2p^6 \ 3s^1$  d. $1s^2 \ 2s^2 \ 2p^6$

22. Which of the following nonmetals is most reactive?
   a. $^6$C  b. $^7$N  c. $^8$O  d. $^9$F

23. Find an atom in the family with Mg that reacts faster than Mg. Write the symbol.

24. Select the number of atoms of K that react with 1 atom of S to form a compound.
   a. 1  b. 2  c. 3  d. 4

25. Write the formula of the compound containing Al and Se.

26. Give the number of elements in the family with Al that are larger in volume than Al.

27. Predict which of the following reacts with Ca to form a compound.
   a. $^{11}$Na  b. $^{12}$Mg  c. $^{17}$Cl  d. $^{10}$Ne

28. Find an element that gains electrons during chemical reactions. Write the symbol.
APPENDIX G

PERMISSION TO USE POSTEST

Subject: Re: 1982 dissertation
Date: Wed, 27 Jun 2001 10:20:51 -0400
From: "Jeffrey Lehman" <***************>
To: anyroddy@iamerica.net

Knight,

Use this email as permission to use the posttest instrument from my dissertation study on the periodic table. Best wishes with your study. If you would like to talk, my office number here at SRU is *************. I will be in and out of the office during the weeks of July 2 and July 9. If I'm not here when you call, just leave a message on my voice mail and I'll get back to you the next time I'm in the office.

Regards,

Jeff Lehman

Knight & Kevin Roddy wrote:

> Hi. My name is Knight Roddy, and I am a doctoral student at Louisiana State University in Baton Rouge. My dissertation topic is the periodic table, and I have a copy of your dissertation at UF. I wanted to obtain permission to use the Posttest that was used in your study. I would love to give you a call to discuss your particular study. If you would, email your phone number and I will give you a call. Thanks,
> Knight anyroddy@iamerica.net
APPENDIX H

ITEM ANALYSIS OF POSTTEST

ATOMIC STRUCTURE
7. Atomic Structure - number of electrons
15. Atomic Structure - number of electrons & protons

PROPERTIES
1. Properties/Physical/Metal vs Nonmetal - which is best conductor
3. Properties/Chemical/Group - element w/ similar chemical properties
20. Properties/General/Group - element least similar in properties
26. Properties/Physical/Atomic size/Group - elements larger in volume

ELECTRON CONFIGURATION
6. Electron config. - electron config. if electron gained
8. Electron config. - element with last electron in a D sublevel
12. Electron config. - element most likely to gain electron
18. Electron config. - element with last electron in a S sublevel
21. Electron config. - electron config. if electron lost

REACTIVITY
4. Reactivity - element that seldom reacts
5. Reactivity/Series - more reactive metal in a series
9. Reactivity/Group - most reactive element within a group
11. Reactivity/Group - less reactive element within a group
13. Reactivity/Metals+Nonmetals - which element reacts with a metal
16. Reactivity/Group - most reactive element within a group
17. Reactivity - least reactive element among different groups
19. Reactivity/Series - more reactive metal in a series
22. Reactivity/Series - which nonmetal in a series is most reactive
23. Reactivity/Group - more reactive element within a group
27. Reactivity/Metals+Nonmetals - what reacts to form a compound

CHEMICAL FORMULAS
2. Chemical formulas - which is correct chemical formula
10. Chemical formulas - which element combines 1 to 1
24. Chemical formulas - # of atoms that reacts with 1 atom of an element
25. Chemical formulas - write chemical formula

GROUPS
3. Properties/Chemical/Group - element w/ similar chemical properties
9. Reactivity/Group - most reactive element within a group
11. Reactivity/Group - less reactive element within a group
16. Reactivity/Group - most reactive element within a group
20. Properties/General/Group - element least similar in properties
23. Reactivity/Group - more reactive element within a group
26. Properties/Physical/Atomic size/Group - elements larger in volume
APPENDIX I

ELEMENT SURVEY
### ELEMENT SURVEY

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>SYM</th>
<th>DESCRIPTION</th>
<th>OCCURRENCES</th>
<th>USES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ELEMENT SURVEY DIRECTIONS**

1. Circle the elements in the list that you have heard of.
2. For the elements that you have heard of, provide as much of the following information as you can:
   - *Description* - Describe what the element physically looks like.
   - *Occurences* - Identify where this element can be found in the natural or manmade world.
   - *Uses* - List uses of the element.
APPENDIX J

APPLICATION FOR EXEMPTION FROM IRB OVERSIGHT

Application for Exemption from IRB (Institutional Review Board)
Oversight for Studies Conducted in Educational Settings

LSU COLLEGE OF EDUCATION

Title of Study: How do selected high school chemistry students understand the nature of the elements, structure, and properties of the periodic table? Can this number change as their participation in a unit study consisting of inquiry-based activities emphasizing construction of innovative science concepts?

Principal Investigator: Knight Robby

Faculty Supervisor: James H. Wadepool
(if student project)

Date of proposed project period: From 1/1/12 To 1/18/12

<table>
<thead>
<tr>
<th>ITEM</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. This study will be conducted in an established or commonly accepted educational setting (schools, universities, summer programs, etc.)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>2. This study will involve children under the age of 18.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>3. This study will involve educational practices such as instrumental strategies or comparison among educational techniques, curricula, or classroom management strategies.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>4. This study will involve educational testing (cognitive, diagnostic, aptitude, achievement.)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>5. This study will use data, documents, or records that existed prior to the study.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>6. This study will use surveys or interviews concerning content that is not related to instructional practices.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>7. This study will involve procedures other than those described in numbers 3, 4, 5, or 6. If yes, describe: Interview's related to the periodic table</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>8. This study will deal with sensitive subjects' and/or subjects' families lives, such as sexual behavior or use of alcohol or other drugs.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>9. Data will be recorded so that the subjects cannot be identified by anyone other than the researcher.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>10. Informed consent of the subject cannot be identified by anyone other than the researcher.</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>11. Assent of minors (under age 18) will be obtained. (Answer if #2 is above is Yes)</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>12. Approval for this study will be obtained from the appropriate authority in the educational setting.</td>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>

Attach an abstract of the study and a copy of the consent form(s) to be used. If your answer(s) to numbers 6 and/or 7 is (are) YES, attach a copy of any surveys, interview protocols, or other procedures to be used.

--- OVER ---
ASSURANCES

As the principal investigator for the proposed research study, I assure that the following conditions will be met:
1. The human subjects are volunteers.
2. Subjects know that they have the freedom to withdraw at any time.
3. The data collected will not be used for any purpose not approved by the subjects.
4. The subjects are guaranteed confidentiality.
5. The subjects will be informed beforehand as to the nature of their activity.
6. The nature of the activity will not cause any physical or psychological harm to the subjects.
7. Individual performances will not be disclosed to persons other than those involved in the research and authorized by the subject.
8. If minors are to participate in this research, valid consent will be obtained beforehand from parents or guardians.
9. All questions will be answered to the satisfaction of the subjects.
10. Volunteers will consent by signature if over the age of 6.

Investigator Statement:

I have read and agree to abide by the standards of the Belmont Report and the Louisiana State University policy on the use of human subjects. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature ___________________________ Date 9/4/01

Faculty Supervisor Statement (required for student research projects):

I have read and agree to abide by the standards of the Belmont Report and the Louisiana State University policy on the use of human subjects. I will supervise the conduct of the proposed project in accordance with federal guidelines for Human Protection. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature ___________________________ Date 9-4-01

Reviewer recommendation:

☐ exemption from IRB oversight. (File this signed application in the Dean’s Office.)

☐ expedited review for minimal risk protocol. (Follow IRB regulations and submit 3 copies to the Dean’s Office.)

☐ full review. (Follow IRB regulations and submit 13 copies to the Dean’s Office.)

Name of Authorized Reviewer: ___________________________ Date 10/25/01

Print name / Signature / Date
ABSTRACT OF STUDY

TITLE: How do selected high school chemistry students' understandings of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics?

INVESTIGATORS:
Student Principal Investigator: Knight Roddy, Doctoral Candidate of Science Education, LSU; Faculty Supervisor/Principal Investigator, Dr. James H. Wandersee, Professor of Science Education, LSU.

DESCRIPTION OF STUDY:
A. PURPOSE OF STUDY.
   The purpose of this research is to study how students learn about the periodic table, and to analyze whether particular instruction methods help students learn about this topic.

B. DESCRIPTION OF THE SUBJECTS.
   The subjects are high school juniors and seniors enrolled in a chemistry course at a small rural public high school near Baton Rouge.

C. JUSTIFICATION FOR USING THIS SUBJECT POPULATION.
   This is the population of students who at the high school level who study the periodic table of the elements.

D. SUBJECT RECRUITMENT PROCEDURES.
   All of the students in the class will be asked to participate in the study. Eight to ten students will be asked to participate in in-depth interviews. Students of low, medium, and high ability will be selected, based on the recommendation of the teacher.

E. DETAILED DESCRIPTION OF THE PROCEDURES TO BE USED.
   Student will be involved in four “hands-on” activities in class, and will complete worksheets that will be collected and recorded with pseudonyms. Six to ten students will be selected to be interviewed on five different occasions during the study. Their pseudonyms will be used to identify them during the interviews. Students will also be tested using an achievement test, which will also use numbers and/or pseudonyms.

F. DESCRIPTION OF THE PROCEDURES FOR OBTAINING CONSENT OF SUBJECTS OR OF PARENTS/GUARDIANS AND ASSENT OF MINOR SUBJECTS.
   Students will receive a letter/consent form describing the research, risks/benefits, procedures, etc. The information in the letter/consent form will be reviewed with students in class, and then students will take the letter home for both parents and students to review and possibly approve.
G. DESCRIPTION OF THE PROCEDURES TO BE USED TO PROTECT THE
IDENTITY AND PRIVACY OF THE SUBJECTS.

All student data will be recorded and reported using pseudonyms in place of their real names.

H. PROCEDURES TO BE USED IN THE STUDY.

Student will be involved in four “hands-on” activities in class, and will complete worksheets that will be collected and recorded with pseudonyms. Six to ten students will be selected to be interviewed on five different occasions during the study. Their pseudonyms will be used to identify them during the interviews. Students will also be tested using an achievement test, which will also use numbers and/or pseudonyms.

I. DEBRIEFING PROCEDURES.

At the end of the study, students who were interviewed will be provided with copies of the concept maps that they constructed during the interviews. All students will be thanked for their participation, and the use of their data will again be explained, emphasizing the protection of their identities.

J. ANY POTENTIAL RISKS TO SUBJECTS AND MEASURES TO BE USED TO MINIMIZE RISKS.

The only possible risk involved is if a student’s identity were revealed and they were embarrassed. All student data will be given pseudonyms or numbers to protect their identity.
March 18, 2002

From: Knight Roddy, Pine County Science Facilitator

To: Parents and Guardians of Students in Mr. Smith’s Chemistry Class

I am writing this letter to obtain permission for your child’s participation in an educational research study being conducted in Mr. Smith’s chemistry class this semester. The purpose of the study is to identify how students learn about the periodic table of the elements, as they participate in lessons making real-life connections. For example, in one activity they will analyze common household products to determine which elements they contain and why. I have collaborated with Mr. Smith in the planning of this research study, and I will be doing it as the formal study for my doctoral degree at LSU. The title of my study is: “How do selected high school chemistry students' understandings of the elements, structure, and periodicity of the Periodic Table change as they participate in a unit study consisting of inquiry-based activities emphasizing construction of innovative science graphics?”

Your child’s work may be collected and studied to better understand how students learn about the periodic table in chemistry. These activities may be video-taped as part of a classroom observation. Your child may be asked to participate in a video/audio taped interview conducted by myself. The interview is optional, and your child has the right to withdraw from it at any time. The interview questions will only focus on your child’s knowledge of science related information. During the interview students will become familiar with concept mapping, a very valuable study skill they can use in the future. Your child’s participation is entirely voluntary and you or your child may withdrawn consent and terminate participation at any time without consequence.

The activities that your child will be participating in will be of great academic benefit to them. It will be part of their graded class work, and will help prepare them for the state-mandated science test in taken in March. The only possible risk involved is if your child’s identify became known, and they were embarrassed. This is very unlikely, as all of the student work that I collect will be recorded with false or fake names to keep their identity a secret. Even the identity of the school is kept secret. The work of some students may be shared with others teachers and researchers in my final report, but again, false or fake names will be used to protect their identity.

As signified below, science teacher Mr. Smith, Principal Roberts, and Superintendent Jones have given their approval for this research study to be conducted. Research of this type is very common, and all of the detailed information above is provided to comply with existing laws that are designed to protect you and your child. Your signature below will indicate your awareness and approval of your child’s participation in educational research within Mr. Smith’s chemistry class during the spring semester of 2002, as outlined above. If you have any questions or concerns about this project, please contact me at the school board office at 777-7777 or home at 777-7778. My faculty advisor, Dr. James Wandersee, can be reached at LSU at 888-8888. Thank you very much for your support in this endeavor.
PARENT/GUARDIAN APPROVAL

I give permission for my child’s ________________________ (name) participation in the above described educational research study that will occur within Mr. Smith’s chemistry class during the spring semester of 2002. I have been fully informed of the above-described procedure, its possible benefits and risks and I give my permission (or participation of my child) in the study.

_________________________  ___________
Signature of Parent or Guardian  Date

_________________________
Name of Parent or Guardian (Print)

STUDENT APPROVAL

I agree to participate in this research study, and understand that my identity will be kept secret. I have been fully informed of the above-described procedure, its possible benefits and risks and I give my permission (or participation of my child) in the study.

_________________________  __________  __________
Signature of Student  Age  Date
Completion Certificate

This is to certify that

Roddy Knight

has completed the Human Participants Protection Education for Research Teams online course, sponsored by the National Institutes of Health (NIH), on 08/31/2001.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

National Institutes of Health
http://www.nih.gov

http://cme.nci.nih.gov/cgi-bin/hsp/cts-cert4.pl

08/31/2001
APPENDIX K

ANALYSIS OF DATA CONCEPT MAP

212
### TABLE L1: STUDENTS’ INITIAL CONCEPTIONS OF THE ELEMENTS (PTLR LEVEL 1)

<table>
<thead>
<tr>
<th>Definition of element</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>E names ID on interview list (4)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100%</td>
</tr>
<tr>
<td>E names ID in C on list (17)</td>
<td>35</td>
<td>41</td>
<td>41</td>
<td>18</td>
<td>35</td>
<td>29</td>
<td>33%</td>
</tr>
<tr>
<td>E symbols given on E survey</td>
<td>80</td>
<td>100</td>
<td>90</td>
<td>70</td>
<td>90</td>
<td>50</td>
<td>80%</td>
</tr>
<tr>
<td>E physical descriptions given on survey</td>
<td>30</td>
<td>40</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>18%</td>
</tr>
<tr>
<td>E occurrences or uses given on survey</td>
<td>30</td>
<td>10</td>
<td>0</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>23%</td>
</tr>
<tr>
<td>E descriptions, occurrences or uses given on survey</td>
<td>50</td>
<td>50</td>
<td>10</td>
<td>40</td>
<td>30</td>
<td>40</td>
<td>37%</td>
</tr>
</tbody>
</table>

C – compound, E – element, ID - identified

The numerical values on the table above represent percentage of elements for which students could provide accurate data.
<table>
<thead>
<tr>
<th>Physical properties *</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard, brittle, gases, soft stuff</td>
<td>S, L, G</td>
<td>Shiny, smooth, hard, heavy, light</td>
<td>Not sure</td>
<td>M, NM, shiny, heavy, not shiny</td>
<td>Metal, gas, liquid</td>
<td></td>
</tr>
<tr>
<td>Metal/Nonmetal</td>
<td>M, NM, ML</td>
<td>M, NM, ML</td>
<td>M, NM, ML</td>
<td>M, NM, ML</td>
<td>M, NM, ML</td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>G, L</td>
<td>S, L, G</td>
<td></td>
<td></td>
<td>G, L</td>
<td></td>
</tr>
<tr>
<td>Phase - Gas</td>
<td>GP 6, 7, 8 and elements C, N, H</td>
<td>Right side of ZZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Atomic Radius</td>
<td>Atomic Mass</td>
<td></td>
<td></td>
<td>Melting point</td>
<td></td>
</tr>
<tr>
<td>Chemical Properties **</td>
<td>Way elements react, stableness</td>
<td>S, L, G</td>
<td>The compounds</td>
<td>Not sure</td>
<td>Will the E react with chemicals</td>
<td>Some of them react</td>
</tr>
<tr>
<td>Reactivity</td>
<td>React/reactive</td>
<td>Reactivity</td>
<td>Reactive</td>
<td>React</td>
<td>React</td>
<td></td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What are some of the physical properties of the elements?”

** Student responses to the direct question, “What are some of the chemical properties of the elements?”
### TABLE L3: STUDENTS’ INITIAL CONCEPTIONS AND EXAMPLES OF GROUPS AND FAMILIES (PTLR LEVEL 3)

<table>
<thead>
<tr>
<th>Group or family *</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements with similar PP &amp; CP</td>
<td>Not sure</td>
<td>Families are M, NM, NG</td>
<td>s, p, d, f</td>
<td>Elements that work together</td>
<td>Elements with something in common</td>
<td></td>
</tr>
<tr>
<td>Numbers across top of PT</td>
<td>Groups</td>
<td>Groups</td>
<td>Blocks</td>
<td>Don’t know</td>
<td>Don’t know</td>
<td>Groups</td>
</tr>
<tr>
<td>Alkali metals (AM)</td>
<td>AM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AM - s</td>
</tr>
<tr>
<td>Alkaline earth Metals (AEM)</td>
<td>AEM</td>
<td></td>
<td>AEM</td>
<td></td>
<td>AEM - s, all M</td>
<td></td>
</tr>
<tr>
<td>Halogens (HA)</td>
<td>HA - gases, all react with M’s to form salt</td>
<td>HA – salt formers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noble gases (NG)</td>
<td>NG - stable, full p sublevel</td>
<td>NG</td>
<td>NG – stable &amp; reactive</td>
<td>GP 8 – doesn’t react</td>
<td>NG – p, all alike, all stable</td>
<td></td>
</tr>
<tr>
<td>Transition elements (TE)</td>
<td>TE</td>
<td></td>
<td></td>
<td></td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H - GP by itself</td>
<td></td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What is a group or family?”
TABLE L4: STUDENTS’ INITIAL CONCEPTIONS OF THE ORGANIZATION OF THE ELEMENTS ON THE PERIODIC TABLE (PTLR LEVEL 4)

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M, NM, ML, NG</strong></td>
<td>Grouped by M, NM, ML, gas</td>
<td>Grouped by M, NM, NG</td>
<td>Grouped into M, NM, ML, NG</td>
<td>Grouped by M, NM, ML</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Location of zigzag line</strong></td>
<td>Incorrectly drawn</td>
<td>Drew correctly</td>
<td>Drew correctly</td>
<td>Somewhere in the p block.</td>
<td>Incorrectly drawn</td>
<td>Drew correctly</td>
</tr>
<tr>
<td><strong>Purpose of zigzag line</strong></td>
<td>Divides M &amp; NM from gases</td>
<td>Separates M from NM</td>
<td>Did not know</td>
<td>Did not know</td>
<td>Did not know</td>
<td>Separates elements</td>
</tr>
<tr>
<td><strong>Location of M &amp; NM</strong></td>
<td>M &amp; NM on left of ZZ</td>
<td>M on left of ZZ, NM on right</td>
<td>M in s block</td>
<td>M on left of PT, NM on right</td>
<td>Not sure</td>
<td>M in GP 1, 2 and d block</td>
</tr>
<tr>
<td><strong>Numbers across the top of PT</strong></td>
<td>Groups</td>
<td>Groups</td>
<td>Blocks</td>
<td></td>
<td></td>
<td>Groups</td>
</tr>
<tr>
<td><strong>Number down the side of PT</strong></td>
<td>Periods</td>
<td>Rows or periods</td>
<td>Sublevels</td>
<td>Don’t remember</td>
<td>Rows</td>
<td>Something to do with EC</td>
</tr>
<tr>
<td><strong>Period or series</strong></td>
<td>Elements going across, left to right</td>
<td>Didn’t know</td>
<td>Sublevels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electron Configuration</strong></td>
<td>Mentions s, p, d; labeled actinide, lanthanide &amp; TE</td>
<td>Labeled actinide</td>
<td>Labeled s, p, d, f blocks.</td>
<td>Labeled s, p, d, f blocks</td>
<td>Mentions s, p, d; colorcoded s-f blocks &amp; some sublevels</td>
<td>Labeled s, p, d, f blocks &amp; some sublevels</td>
</tr>
<tr>
<td><strong>Atomic number</strong></td>
<td>Organized by atomic number</td>
<td>Organized by atomic number</td>
<td>Atomic number increases left to right</td>
<td>In order of atomic number</td>
<td>Ordered by atomic number</td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>By their properties</td>
<td>Organized into groups, periods, rows</td>
<td>Grouped by how reactive they are</td>
<td></td>
<td></td>
<td>Grouped as AM, AEM, NG</td>
</tr>
</tbody>
</table>

TABLE L5: STUDENTS’ CONCEPTIONS AND EXAMPLES OF PHYSICAL AND CHEMICAL PROPERTIES (PTLR LEVEL 2) AFTER ACTIVITY ONE

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>**Physical properties *</td>
<td>Color, phase, M/NM</td>
<td>Color, phase, M/NM</td>
<td>Color, phase</td>
<td>Color, phase, M/NM</td>
<td>Not sure</td>
<td>Color, phase, M/NM</td>
</tr>
<tr>
<td><strong>Metal/Nonmetal</strong></td>
<td>M, NM</td>
<td>M, NM</td>
<td>M, NM</td>
<td>M, NM</td>
<td>M, NM</td>
<td>M, NM</td>
</tr>
<tr>
<td>M - Phase</td>
<td>All S, except Hg</td>
<td>Most are S</td>
<td>Aren’t G</td>
<td>Most are S</td>
<td>Most are S</td>
<td>Most are S, except Hg</td>
</tr>
<tr>
<td>NM - Phase</td>
<td>Equally S &amp; G; only 1 L</td>
<td>G, S, 1L</td>
<td>Most are S</td>
<td>G or L</td>
<td>S, L, G; more L than S.</td>
<td>10 G, 10 S, 1 L</td>
</tr>
<tr>
<td>M - Color</td>
<td>Most are silver, except Cu, Au</td>
<td>Most are silver, except Cu, Au</td>
<td>Most are silver, except Cu, Au</td>
<td>Most are silver, except Cu, Au</td>
<td>Most are silver, except Cu, Au</td>
<td>Most are silver, except Cu, Au</td>
</tr>
<tr>
<td>NM - Color</td>
<td>Silver or some other color</td>
<td>Colorless or silver</td>
<td>Can be different colors</td>
<td>Most are silver, except Cu, Au</td>
<td>Some silver, red, purple, green</td>
<td>Some silver, red, purple, green</td>
</tr>
<tr>
<td>Phase – Gas</td>
<td>GP 8, L shape, H</td>
<td>GP 8, H</td>
<td>GP 8, L shape, H</td>
<td>NG, H is a NG</td>
<td>GP 8, L shape, H</td>
<td>GP 8, L shape, H</td>
</tr>
<tr>
<td>Phase – Liquid</td>
<td>Hg, Br</td>
<td>Hg, Br</td>
<td>Hg, Br</td>
<td>F, Cl, Br</td>
<td>Hg, Br</td>
<td>Hg, Br</td>
</tr>
<tr>
<td>Phase – Solid</td>
<td>Everything else</td>
<td>Most of PT</td>
<td>All rest</td>
<td>To left of ZZ</td>
<td>I, B, C</td>
<td>Most metals are silver</td>
</tr>
<tr>
<td>Color – silver</td>
<td>Most all E</td>
<td>Most M, except Cu, Au</td>
<td>To the left</td>
<td>Most M, except Cu, Au</td>
<td>Most M, except Cu, Au</td>
<td>Most M, except Cu, Au</td>
</tr>
<tr>
<td>Color – colorless</td>
<td>Gases, except Cl</td>
<td>Gases</td>
<td>To the right</td>
<td>Most gases</td>
<td>Most gases</td>
<td>Most gases</td>
</tr>
<tr>
<td>Color- colored</td>
<td>Cl, Cu, Au, I</td>
<td>Cl, Se, Cu, Au</td>
<td>NM can be different colors</td>
<td>Noble gases, C, I, Br</td>
<td>I, NG, Br, Se</td>
<td>C, some nonmetals</td>
</tr>
<tr>
<td>Chemical Properties **</td>
<td>Element reactions</td>
<td>Don’t know</td>
<td>Reacts chemically</td>
<td>How reactive they are</td>
<td>Some can react with others</td>
<td>How they react to other elements</td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What are some of the physical properties of the elements?”

** Student responses to the direct question, “What are some of the chemical properties of the elements?”
TABLE L6: STUDENTS’ CONCEPTIONS AND EXAMPLES OF GROUPS AND FAMILIES (PTLR LEVEL 3) AFTER ACTIVITY ONE

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group or family *</td>
<td>Elements with similar PP &amp; CP.</td>
<td>Elements with similar reactivity</td>
<td>AM, AEM, HA, NG. Families have same basic characteristics.</td>
<td>Families are s, p, d, f</td>
<td>Have almost the same CP, can react with each other.</td>
<td>Got the same characteristics</td>
</tr>
<tr>
<td>Numbers across top of PT</td>
<td>Groups</td>
<td>Groups</td>
<td>Classify E into blocks</td>
<td>Groups</td>
<td>Groups</td>
<td>Groups</td>
</tr>
<tr>
<td>GP 1 – Alkali Metals (AM)</td>
<td>AM – highly reactive</td>
<td>GP 1 – very reactive</td>
<td>Block 1, AM - metals, very reactive</td>
<td>GP 1 – highly reactive, green background</td>
<td>AM – very reactive, green background</td>
<td>AM – react to oxygen and water</td>
</tr>
<tr>
<td>GP 2 - Alkaline Earth Metals (AEM)</td>
<td>AEM - less reactive than AM &amp; HA</td>
<td>GP 2 - active</td>
<td>Block 2, AEM - active</td>
<td>GP 2 - active</td>
<td>AEM - reactive</td>
<td>AEM</td>
</tr>
<tr>
<td>GP 3-5</td>
<td>GP 3-6 moderately active</td>
<td>Block 3-6 – moderately active</td>
<td>GP 3-6 - react</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 7 - Halogens (HA)</td>
<td>GP 7 - reacts with M to form salts. HA - highly reactive.</td>
<td>GP 7, HA – very active, all salt formers</td>
<td>Block 7, HA - active</td>
<td>GP 7 - inert</td>
<td>GP 7 – reacts with M to form salt</td>
<td></td>
</tr>
<tr>
<td>GP 8 - Noble Gases (NG)</td>
<td>Stable</td>
<td>GP 8, NG – all gases, unreactive</td>
<td>Block 8, NG – all gases, stable, unreactive</td>
<td>GP 8, NG - doesn’t react</td>
<td>NG – highly reactive, all are gases</td>
<td>NG – all gases, don’t need to gain or lose</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td></td>
<td></td>
<td></td>
<td>H is a NG</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Student responses to the direct question, “What is a group or family?”
TABLE L7: STUDENT CONCEPTIONS OF THE ORGANIZATIONAL BASIS OF THE ELEMENTS ON THE PERIODIC TABLE (PTLR LEVEL 4) AFTER ACTIVITY ONE

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M, NM, ML, NG</strong></td>
<td>M or NM</td>
<td>Classified by M or NM</td>
<td>Classified as M, NM, NG, HA</td>
<td>E are classified as M or NM</td>
<td>M and NM are separated by ZZ</td>
<td></td>
</tr>
<tr>
<td><strong>Location of zig-zag line</strong></td>
<td>Drew correctly</td>
<td>Drew correctly</td>
<td>Drew correctly</td>
<td>Drew correctly</td>
<td>Drew correctly</td>
<td>Drew correctly</td>
</tr>
<tr>
<td><strong>Purpose of zig-zag line</strong></td>
<td>Separates M from NM</td>
<td>Separates M from NM</td>
<td>Separates M from NM</td>
<td>Separates M from NM</td>
<td>Separates M from NM</td>
<td>Separates M from NM</td>
</tr>
<tr>
<td><strong>Location of M &amp; NM</strong></td>
<td>M on left of ZZ, NM on right</td>
<td>M on left of ZZ, NM on right</td>
<td>M on left of ZZ, NM on right</td>
<td>M on left of ZZ, NM on right</td>
<td>M on left of ZZ, NM on right</td>
<td>M on left of ZZ, NM on right</td>
</tr>
<tr>
<td><strong>Numbers across the top of PT</strong></td>
<td>Groups</td>
<td>Groups</td>
<td>Blocks</td>
<td>Groups</td>
<td>Groups</td>
<td>Groups</td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td>Organized into GPs - AM, AEM, HA, NG</td>
<td>Grouped based on reactivity</td>
<td>Grouped by block 1, 2, etc. (GP 1, 2, etc.)</td>
<td>Grouped by group number</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Family</strong></td>
<td>Organized by families - AM, AEM, HA, NG</td>
<td>Organized in families</td>
<td>Classified as families (s, p, d, f)</td>
<td></td>
<td>AM, AEM, NG are each grouped together</td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Organized by properties into patterns</td>
<td>Grouped based on reactivity</td>
<td>E organized in patterns, have properties</td>
<td>E classified by highly reactive or inert, NG or ML</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

# TABLE L8 – IDENTIFICATION OF ELEMENTS FROM SELECTED COMPOUNDS IN TOOTHPASTE PRODUCT AFTER ACTIVITY TWO (LEVEL 1)

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dicalcium Phosphate Dihydrate (Ca, P, O, H)</td>
<td>Ca, P, O, H</td>
<td>Ca, P, O, H</td>
<td>Ca, P</td>
<td>Ca, P</td>
<td>Ca, P, O</td>
<td>Ca, P, O, H</td>
<td>P</td>
</tr>
<tr>
<td>Water (H, O)</td>
<td>H$_2$O</td>
<td>H, O</td>
<td>H, O</td>
<td>H, O</td>
<td>H, O</td>
<td>H, O</td>
<td></td>
</tr>
<tr>
<td>Sodium Lauryl Sulfate (Na, S, O)</td>
<td>Na, S, O</td>
<td>S, O</td>
<td>S</td>
<td>Na, S, O</td>
<td>Na, S</td>
<td>Na, S</td>
<td></td>
</tr>
<tr>
<td>Total Elements Identified</td>
<td>13/13 (100%)</td>
<td>12/13 (92%)</td>
<td>6/13 (46%)</td>
<td>12/13 (92%)</td>
<td>4/13 (31%)</td>
<td>8/13 (62%)</td>
<td>9.2/13 (71%)</td>
</tr>
</tbody>
</table>

(All abbreviations are element symbols.)
<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>ID H, C, N, O as basic, colored yellow, most important</td>
<td>ID H, C, N, O as basic, colored red, most important</td>
<td>ID H, C, N, O as basic, colored yellow, most important</td>
<td>ID H, C, N, O as basic, colored yellow, most important</td>
<td>ID H, C, N, O as basic, colored yellow, most important</td>
<td>ID H, C, N, O as basic, colored yellow, most important</td>
</tr>
<tr>
<td>Macro</td>
<td>ID Na, Mg, K, Ca, P, S, Cl as macro, colored red. Four are in s block.</td>
<td>ID macro as a category</td>
<td>ID Na, Mg, K, Ca, P, S, Cl incorrectly as micro, colored red.</td>
<td>ID macro as a category, most important</td>
<td>ID Na, Mg, K, Ca as macro, colored red.</td>
<td>Na, Mg, K, Ca colored red. Tentatively ID as macro.</td>
</tr>
<tr>
<td>Micro</td>
<td>ID 3d as micro, colored green</td>
<td>ID micro as a category</td>
<td>ID some of 3d incorrectly as macro, colored green.</td>
<td>ID micro as a category</td>
<td>ID micro as a category</td>
<td>ID micro as a category. ID 3d and colored green, but not ID as micro.</td>
</tr>
<tr>
<td>Trace</td>
<td>ID trace as orange</td>
<td>ID trace as orange, no elements colored</td>
<td>ID trace as a category</td>
<td>ID trace as a category</td>
<td>ID trace as a category</td>
<td>ID trace as a category</td>
</tr>
<tr>
<td>Inert</td>
<td>ID GP 8 as inert, colored blue</td>
<td>ID NG as inert, because they don’t react. Not colored</td>
<td>ID inert as blue, no elements colored. GP 8 not nutrients, not in products</td>
<td>ID inert as a category</td>
<td>Doesn’t ID inert as category, but states NG aren’t nutrients because they aren’t reactive</td>
<td>ID inert as a category</td>
</tr>
<tr>
<td>Bioxins</td>
<td>ID 4f as biotoxins, colored brown. Harmful</td>
<td>ID 4f as biotoxins, not colored. Harmful</td>
<td>ID 4f as biotoxins, colored brown</td>
<td>ID 4f as biotoxins, colored brown</td>
<td>Doesn’t ID biotoxins as a category, ID 4f and colors it brown, no ID.</td>
<td>ID 4f as biotoxins, colored brown</td>
</tr>
<tr>
<td>Radioactive</td>
<td>ID 5f, 43, 84-86 as radioactive, colored purple. Harmful</td>
<td>ID 5f, 85-88, 104-109 as radioactive, colored purple. Harmful</td>
<td>ID 5f &amp; Pm as radioactive, colored purple. Harmful</td>
<td>ID radioactive as a category. Harmful</td>
<td>ID radioactive as category Colors 85-89, 104-109 purple, not ID as radioactive. Harmful</td>
<td>ID 5f as radioactive, colored purple. Harmful</td>
</tr>
</tbody>
</table>

GP – group, ID – identified, NG – noble gas. (All other abbreviations are element symbols)
<table>
<thead>
<tr>
<th>S1</th>
<th>Metals and Nonmetals</th>
<th>S2</th>
<th>Nonmetals and Nonmetals</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M &amp; NM form ionic C’s, they share electrons</td>
<td>M &amp; NM, M always in front of NM</td>
<td>M &amp; NM</td>
<td>M &amp; NM</td>
<td>M &amp; NM</td>
<td>M &amp; NM Transition M &amp; NM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M &amp; NM</td>
<td>NM &amp; NM form covalent C, don’t share electrons</td>
<td></td>
<td></td>
<td></td>
<td>NM &amp; NM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O combines with E’s to form C with oxide and -ate at the end</td>
<td>O used to form the ionic C. O compounds have -ate at end</td>
<td>E’s have reactions, are usually formed using O.</td>
<td>Most E combine with O to form C, with oxide &amp; -ate at end.</td>
<td>O can combine with all E</td>
<td>O reacts with a lot of E’s</td>
<td></td>
</tr>
<tr>
<td>GP 1 &amp; GP 7</td>
<td>GP 1 &amp; GP 7. Very active combines with very active.</td>
<td>GP 1 &amp; GP 7 Sodium chloride</td>
<td>GP 1 (lose electrons) &amp; GP 7 (gain electrons)</td>
<td>GP 1 &amp; GP 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 2 &amp; GP 6</td>
<td>GP 2 &amp; GP 6. Least active combines with least active.</td>
<td>GP 2 &amp; GP 6 (M, lose electrons) &amp; GP 6 (gain electrons)</td>
<td>GP 2 &amp; GP 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>GP 3 &amp; GP 5</td>
<td>Mg &amp; O, K &amp; O, K &amp; I. Ionic: Mg &amp; I. Covalent: Mg &amp; O.</td>
<td>GP 2 &amp; GP 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C – compound, E - elements, GP – group, I – Iodine, K – Potassium, M - metals, Mg – Magnesium, NM – nonmetals, O - oxygen
### TABLE L11: STUDENT EXAMPLES OF GROUPS AND FAMILIES (PTLR LEVEL 3) AFTER ACTIVITY TWO

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP 1 – Alkali Metals (AM)</td>
<td>GP 1 – very active</td>
<td>GP 1 – very active</td>
<td>GP 1, AM – highly reactive</td>
<td>GP 1 – highly reactive</td>
<td>GP 1 – highly reactive</td>
<td></td>
</tr>
<tr>
<td>GP 2</td>
<td>GP 2 – active</td>
<td>GP 2 – active</td>
<td>GP 2 - reactive</td>
<td>GP 2- active</td>
<td>GP 2 – active</td>
<td></td>
</tr>
<tr>
<td>GP 3-5</td>
<td>GP 3-5 – Just reactive</td>
<td>GP 3-5 Moderately reactive</td>
<td>GP 2 - reactive</td>
<td>GP 2- active</td>
<td>GP 2 – active</td>
<td></td>
</tr>
<tr>
<td>GP 6</td>
<td>GP 6 – active</td>
<td>GP 6 – active</td>
<td>GP 6 - reactive</td>
<td>GP 6 – active</td>
<td>GP 6 – active</td>
<td></td>
</tr>
<tr>
<td>GP 7 - Halogens (HA)</td>
<td>GP 7 – very active</td>
<td>GP 7 – very active</td>
<td>GP 7, HA – highly reactive</td>
<td>GP 7 – highly reactive</td>
<td>GP 7 – active?</td>
<td></td>
</tr>
<tr>
<td>GP 8 - Noble Gases (NG)</td>
<td>NG, GP 8 – stable, not reactive</td>
<td>GP 8 - unreactive</td>
<td>GP 8 - unreactive</td>
<td>GP 8 - inert</td>
<td>NG are not highly reactive</td>
<td></td>
</tr>
</tbody>
</table>

TABLE L12: STUDENT CONCEPTIONS OF THE ORGANIZATIONAL BASIS OF THE ELEMENTS ON THE PERIODIC TABLE (PTLR LEVEL 4) AFTER ACTIVITY TWO

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>3d sublevel</td>
<td>3d</td>
<td>3d</td>
<td>3d</td>
<td></td>
<td>3d</td>
<td></td>
</tr>
<tr>
<td>4f sublevel</td>
<td>4f</td>
<td>4f</td>
<td>4f</td>
<td></td>
<td>4f</td>
<td></td>
</tr>
<tr>
<td>5f sublevel</td>
<td>5f</td>
<td>5f</td>
<td>5f</td>
<td></td>
<td>5f</td>
<td></td>
</tr>
<tr>
<td>Nutritional categories</td>
<td>E grouped by nutritional value.</td>
<td>E organized in nutrient categories</td>
<td>E classified by how much we need them</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactivity</td>
<td>E grouped by the way they react.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td>Organized in GP’s</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E – elements, GP – groups
TABLE L13: STUDENT EXAMPLES OF ELEMENTS IN PRODUCTS (PTLR LEVEL 1) AFTER ACTIVITY THREE

<table>
<thead>
<tr>
<th>Products and E contained in them</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caulking – Si</td>
<td>Bottled water - F</td>
<td>Dandruff shampoo – Se</td>
<td>Bleach – N, H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt substitute – K or Cl, not Na Batteries - Ti</td>
<td>Salt – NaCl</td>
<td>Bottled water – F, H, O</td>
<td>Soap – 10 different E</td>
<td>Most all of them have O</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Caulking – Si</td>
<td>Toothpaste - F</td>
<td>Bleach – N, H</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boric acid – B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aluminum foil Fishing lead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 most commonly occurring E in products</td>
<td>H, Na, Ca, O, Cl</td>
<td>H, Na, Ca, O, Cl</td>
<td>Na, Ca, O, Cl, C</td>
<td>Na, Ca, O, C</td>
<td>H, Na, Ca, O, Cl</td>
<td></td>
</tr>
<tr>
<td>Why were they commonly occurring?</td>
<td>They can react good with other E</td>
<td>You really need those E</td>
<td>We use them in our everyday life</td>
<td></td>
<td>All of them in an active family</td>
<td></td>
</tr>
</tbody>
</table>

C – compound, E - elements, GP – group, I – Iodine, K – Potassium, M - metals, Mg – Magnesium, NM – nonmetals, O - oxygen
**TABLE L14: STUDENT CONCEPTIONS OF REACTIVITY AND REACTIVITY PATTERNS ON THE PERIODIC TABLE (CHEMICAL PROPERTIES, PTLR LEVEL 2) AFTER ACTIVITY THREE**

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactivity</strong> *</td>
<td>Ability of E to combine with each other</td>
<td>How E’s react with other E’s. A CP</td>
<td>How an E reacts, in a chemical reaction</td>
<td>The way E’s react with each other</td>
<td>When NM &amp; M react together.</td>
<td>When 2 E combine they form a product</td>
</tr>
<tr>
<td><strong>Metals and</strong></td>
<td>M &amp; NM form ionic C</td>
<td>M &amp; NM form ionic C</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM is bionic</td>
</tr>
<tr>
<td><strong>Nonmetals</strong></td>
<td>M &amp; NM form ionic C</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM form ionic</td>
<td>M &amp; NM is bionic</td>
</tr>
<tr>
<td><strong>Nonmetals and</strong></td>
<td>NM &amp; NM form ionic C</td>
<td>NM &amp; NM form ionic</td>
<td>NM &amp; NM form ionic (i.e. phosphate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Oxygen</strong></td>
<td>O combines with lots of E’s. O is most reactive E.</td>
<td>Most E combined with O</td>
<td>Most E is ionic</td>
<td>Most products have O</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>elements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GP 1 &amp; GP 7</strong></td>
<td>GP 1 &amp; GP 7</td>
<td>GP 1 &amp; GP 7 is ionic.</td>
<td>GP 1 &amp; GP 7 is ionic.</td>
<td>GP 1 &amp; GP 7 is ionic.</td>
<td>GP 1 &amp; GP 7 is ionic.</td>
<td>GP 1 &amp; GP 7 is ionic.</td>
</tr>
<tr>
<td><strong>GP 2 &amp; GP 6</strong></td>
<td>GP 2 &amp; GP 6</td>
<td>GP 2 &amp; GP 6 is ionic.</td>
<td>GP 2 &amp; GP 6 is ionic.</td>
<td>GP 2 &amp; GP 6 is ionic.</td>
<td>GP 2 &amp; GP 6 is ionic.</td>
<td>GP 2 &amp; GP 6 is ionic.</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Phosphorus, P&amp;O Both covalent</td>
<td>Phosphorus, P&amp;O Both covalent</td>
<td>Phosphorus, P&amp;O Both covalent</td>
<td>Phosphorus, P&amp;O Both covalent</td>
<td>Phosphorus, P&amp;O Both covalent</td>
<td>Phosphorus, P&amp;O Both covalent</td>
</tr>
</tbody>
</table>

C – compound, CP – chemical property, E - elements, GP – group, M - metals, NM – nonmetals, O – oxygen, P - phosphorus

* Student response the direct question, “What is reactivity?”
<table>
<thead>
<tr>
<th>E in a Group or Family *</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar PP &amp; CP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Similar with each other.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have same reactivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I don’t know</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M or MN, how active they are</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 1 – very active, all M, all silver</td>
<td>GP 1 – very active</td>
<td>GP 1 - highly reactive, more reactive as you go down</td>
<td>GP 1 – highly reactive</td>
<td>GP 1 – M</td>
<td>GP 1 – highly reactive</td>
<td></td>
</tr>
<tr>
<td>GP 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 2 – active, all M, all silver</td>
<td>GP 2 – active</td>
<td>GP 2 - reactive</td>
<td>GP 2 - active</td>
<td></td>
<td>GP 2 – active, metals</td>
<td></td>
</tr>
<tr>
<td>GP 3-5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5 – least active</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5 moderately active</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5 moderately reactive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5 moderately active</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5 – ?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 6 – active. O is the most reactive</td>
<td>GP 6 – active</td>
<td>GP 6 - reactive, more reactive as you go up</td>
<td>GP 6 – active</td>
<td></td>
<td>GP 6 - active</td>
<td></td>
</tr>
<tr>
<td>GP 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 7 – very active</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 7 – very active, all salt formers</td>
<td>GP 7 – highly reactive</td>
<td>GP 7 – highly reactive</td>
<td>GP 7 - NM</td>
<td>GP 7 – highly reactive, nonmetals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 8 - Noble Gases (NG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 8 – stable, all gases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 8 – unreactive, inert, all gases</td>
<td>GP 8 - unreactive</td>
<td>GP 8 - inert</td>
<td></td>
<td>GP 8 – stable, gases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


* Student response the direct question, “What do the elements in a group or family have in common?”
TABLE L16: STUDENT CONCEPTIONS OF THE ORGANIZATIONAL BASIS OF THE ELEMENTS ON THE PERIODIC TABLE (PTLR LEVEL 4) AFTER ACTIVITY THREE

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups</td>
<td>Organized by groups (1, 2, etc.)</td>
<td>By groups and families</td>
<td>S3</td>
<td>S4</td>
<td>S5</td>
<td>S6</td>
</tr>
<tr>
<td>Reactivity</td>
<td>PT has patterns in reactivity, organized by CP</td>
<td>How they react with other E</td>
<td>By how reactive they are</td>
<td>By how active they are</td>
<td>By how active they are</td>
<td>By groups</td>
</tr>
<tr>
<td>Other</td>
<td>By physical properties</td>
<td>M &amp; NM</td>
<td>By TE, M, NM, NG, radioactive</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TABLE L17: STUDENT OBSERVATIONS OF THE LINE OF ELEMENT CARDS DURING ACTIVITY FOUR

<table>
<thead>
<tr>
<th></th>
<th>S1 &amp; S3</th>
<th>S2 &amp; S4</th>
<th>S5 &amp; Partner</th>
<th>S6 &amp; Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Color</strong></td>
<td>Green in pairs, almost all in containers. Yellow in fours. Grey is GP 7. Silvers by browns.</td>
<td>2 green blocks follow behind each gas</td>
<td>Background colors of first 2 and last 2 green, and color of NG is black. Green always first in sequence.</td>
<td>Some background colors are paired</td>
</tr>
<tr>
<td><strong>Phase</strong></td>
<td>Repeating sequence is M/NM/G. Picture of NG shown as a G.</td>
<td>2 green blocks follow each gas.</td>
<td></td>
<td>After every 7 there is a gas. 3 gases together: N, O, F.</td>
</tr>
<tr>
<td><strong>Atomic number</strong></td>
<td></td>
<td></td>
<td></td>
<td>Atomic number and mass increase</td>
</tr>
<tr>
<td><strong>GP 1 and/or GP 2</strong></td>
<td>Almost every green E is in a container</td>
<td>2 green blocks follow each gas. Highly reactive E after each NG.</td>
<td>Background colors of first 2 and last 2 green. Green always first in sequence.</td>
<td>After every NG there is a M in water</td>
</tr>
<tr>
<td><strong>Noble gases (NG)</strong></td>
<td>After every 7 E there is a NG. Picture of NG shown as a G.</td>
<td>NG separated by eights</td>
<td>NG background color is black. NG is 8th E</td>
<td>After every NG there is a M in water</td>
</tr>
<tr>
<td><strong>Numerical pattern</strong></td>
<td>After every 7 E there is a NG.</td>
<td>NG separated by eights</td>
<td>NG is 8th E</td>
<td>After every 7 E there is a gas. Some E missing from the numerical sequence</td>
</tr>
</tbody>
</table>

TABLE L18: PATTERN SEQUENCES THAT STUDENTS CREATED FROM THE LINE OF ELEMENT CARDS DURING ACTIVITY FOUR

S1 & S3

| Li | Be | B | C | N | O | F | Ne | Na | Mg | Al | Si | P | S | Cl | Ar | K | Ca | Ga | Ge | As | Se | Br | Kr | Rb | Sr | In | Sn | Sb | Te | I | Xe | Cs | Ba |
|----|----|---|---|---|---|---|----|----|----|----|----|----|---|---|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Metal | Nonmetal | Gas | Metal | Nonmetal | Metal | Gas | Nonmetal | L & G | Metal | Nonmetal | L & G | Metal |

S2 & S4

| Li | Be | B | C | N | O | F | Ne | Na | Mg | Al | Si | P | S | Cl | Ar | K | Ca | Ga | Ge | As | Se | Br | Kr | Rb | Si | In | Sn | Sb | Te | I | Xe | Cs | Ba |
|----|----|---|---|---|---|---|----|----|----|----|----|----|---|---|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| HRE | NG | HRE | HRE | HRE | HRE | HRE | HRE | HRE | HRE | HRE | HRE | HRE | HRE |

S5 & partner

| Li | Be | B | C | N | O | F | Ne | Mg | Al | Si | P | S | Cl | Ar | K | Ca | Ga | Ge | As | Se | Br | Kr | Rb | Sr | In | Sn | Sb | Te | I | Xe | Cs | Ba |
|----|----|---|---|---|---|---|----|----|----|----|----|----|---|---|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| NG | HRE | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG |

S6 & partner

| Li | Be | B | C | N | O | F | Ne | Mg | Al | Si | P | S | Cl | Ar | K | Ca | Ga | Ge | As | Se | Br | Kr | Rb | Si | In | Sn | Sb | Te | I | Xe | Cs | Ba |
|----|----|---|---|---|---|---|----|----|----|----|----|----|---|---|----|----|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| HRE | NG | HRE | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG | NG |

G – gas, HRE – highly reactive element, L – liquid, NG – noble gas
<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atomic number</strong></td>
<td>*In order of atomic number</td>
<td>*By atomic number</td>
<td>*By the atomic mass &amp; atomic number</td>
<td>*Arranged according to atomic number</td>
<td>*Atomic number</td>
<td>*Atomic number</td>
</tr>
<tr>
<td><strong>Sublevels or series</strong></td>
<td><strong>Sublevels</strong></td>
<td>*Sublevels Series 2. 1s, 2s, 2p, 3s, 3p, 4s</td>
<td>*Sublevels</td>
<td>3d, 4d, 5d</td>
<td>*Sublevels</td>
<td>Sublevels</td>
</tr>
<tr>
<td><strong>S, p, d, f sublevel blocks</strong></td>
<td>*In their s, p, d, f blocks</td>
<td>Main blocks (d block) p section</td>
<td>s block – highly reactive metals, d block</td>
<td>*Sublevel blocks</td>
<td>Sublevel blocks</td>
<td>*Sublevel blocks S’s, P’s</td>
</tr>
<tr>
<td><strong>Background colors of groups</strong></td>
<td>Colors of background will help</td>
<td>Putting all colors together</td>
<td></td>
<td></td>
<td></td>
<td>Color of background of cards</td>
</tr>
<tr>
<td><strong>Groups</strong></td>
<td>Groups</td>
<td>Groups 3, 4, 5, 6, 7, 8</td>
<td>*Groups Noble gases</td>
<td>*Groups</td>
<td>*Groups</td>
<td>Groups</td>
</tr>
<tr>
<td><strong>Metals/Nonmetals</strong></td>
<td></td>
<td></td>
<td></td>
<td>Highly reactive metals</td>
<td>Metals, nonmetal side</td>
<td></td>
</tr>
</tbody>
</table>

**Student responses to the direct question, “What’s your method of putting the table back together?”**

**Statements made by students during the reconstruction process.**

* Primary strategy used during reconstruction of the table.
TABLE L20: SEQUENCES STUDENTS USED TO RECREATE THE PERIODIC TABLE DURING INTERVIEW FIVE

<table>
<thead>
<tr>
<th>S2</th>
<th>S &amp; p blocks (spaced apart) partially formed in order of atomic #: 2s, 2p, 3s, 3p, 4s &gt; 3d inserted &gt; 4p, 5s, 4d, 5p, 6s, 5d, 6p, 7s in order of atomic number &gt; 4f, 5f inserted</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>S &amp; p blocks (spaced apart) partially formed in order of atomic #: 2s, 2p, 3s, 3p, 4s &gt; 5s, 6s, &gt; 4p, 5p in order of atomic number &gt; inserts 3d, 4d, 5d (d block completed) &gt; 6p, 7s &gt; 4f, 5f inserted, didn’t realign 3d, 4d</td>
</tr>
<tr>
<td>S1</td>
<td>S &amp; p blocks (spaced apart) partially formed in order of atomic #: 2s, 2p, 3s, 3p, 4s &gt; 3d inserted &gt; 5s, 6s, 7s (s block completed) &gt; GP 8 &gt; 4d, 5d (d block completed) &gt; 4p, 5p, 6p by group and atomic number (p block completed) &gt; 4f, 5f inserted</td>
</tr>
<tr>
<td>S3</td>
<td>2s, 2p (not spaced) &gt; s &amp; p blocks partially formed by group &amp; sublevel: 3s, 4s, 5s, GP 7, GP 8 &gt; separated s &amp; p blocks &gt; 3p completed &gt; 3d inserted &gt; 4p, 4d, 5p, 6s, 5d, 6p, 7s in order of atomic number &gt; 4f, 5f inserted</td>
</tr>
<tr>
<td>S5</td>
<td>2s, 2p (spaced apart) &gt; s &amp; p blocks partially formed by group &amp; sublevel: 3s, 4s, 3p &gt; 3d inserted &gt; 4p, 3s, 4d, 5p, 6s, 5d, 6p, 7s in order of atomic # &gt; 4f, 5f inserted &gt; 3d, 4d not realigned</td>
</tr>
<tr>
<td>S4</td>
<td>All elements in order of atomic # &gt; 2s, 3s, 4s pulled from order to form s block &gt; GP 8 formed &gt; 2p, 3p pulled from order to form p block, joined to s block &gt; 5s, 6s &gt; GP 8 joined to p block &gt; insert 3d, 4d, 5d (d block completed) &gt; 4p, 5p &gt; 6p &amp; 7s incorrectly placed under 5d &gt; 4f inserted &gt; 5f added next to 7s, which is out of place &gt; d &amp; p blocks not realigned</td>
</tr>
</tbody>
</table>

S block   P block   D block   F block
TABLE L21: STUDENT CONCEPTIONS AND EXAMPLES OF PHYSICAL AND CHEMICAL PROPERTIES (PTLR LEVEL 2) AFTER ACTIVITY FOUR

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>**properties *</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>properties *</td>
<td>Color, phase, M/NM</td>
<td>Color, phase, M/NM</td>
<td>Color, phase, M/NM</td>
<td>Color, phase, M/NM</td>
<td>Color, M/NM</td>
<td>Color, L, G or S, M/NM</td>
</tr>
<tr>
<td>Patterns of</td>
<td>M - silver</td>
<td>M – silver, solid</td>
<td>Gases – NG, some in GP 5, 6, 7</td>
<td>M – silver</td>
<td>M - silver</td>
<td>M - silver</td>
</tr>
<tr>
<td>Physical</td>
<td>NM – silver, colorless, &amp; different</td>
<td>colors vary</td>
<td>Gases – NG, some in GP 5, 6, 7</td>
<td>L shape</td>
<td>M - silver</td>
<td>M - silver</td>
</tr>
<tr>
<td>Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atomic size</td>
<td>Increases down a GP, decreases left to</td>
<td>Increases down a GP, decreases across a</td>
<td>Increases down a GP, decreases left to</td>
<td>Increases left to right</td>
<td>Increases down a GP</td>
<td>Increases down a GP</td>
</tr>
<tr>
<td>Chemical</td>
<td>Reactivity, EC, OX</td>
<td>Reactivity, outer sublevel, outer</td>
<td>Reactivity, sublevels, OX</td>
<td>Reactivity</td>
<td>If they are alkali, AEM, inert, if they</td>
<td>Reactivity</td>
</tr>
<tr>
<td>Properties **</td>
<td></td>
<td>shell electrons, OX</td>
<td></td>
<td></td>
<td>react</td>
<td></td>
</tr>
<tr>
<td>Oxidation number</td>
<td>OX</td>
<td>OX</td>
<td>OX</td>
<td>OX</td>
<td>OX</td>
<td>OX</td>
</tr>
<tr>
<td>Oxidation number</td>
<td>(OX)</td>
<td>(OX)</td>
<td>(OX)</td>
<td>(OX)</td>
<td>(OX)</td>
<td>(OX)</td>
</tr>
<tr>
<td>Outer sublevel</td>
<td>OS</td>
<td>OS</td>
<td>OS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outer shell</td>
<td>OSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrons (OSE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What are some of the physical properties of the elements?”

** Student responses to the direct question, “What are some of the chemical properties of the elements?”
TABLE L22: STUDENT CONCEPTIONS AND EXAMPLES OF GROUPS AND FAMILIES (PTLR LEVEL 3) AFTER ACTIVITY FOUR

<table>
<thead>
<tr>
<th>Group or family *</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>E’s with similar PP &amp; CP. E in some GP’s have Different color, phase, reactivity</td>
<td>E’s with similar reactivity</td>
<td>E that have similar properties</td>
<td>E that have similar properties</td>
<td>E that can react with each other.</td>
<td>E with similar things in common</td>
<td></td>
</tr>
<tr>
<td><strong>Numbers across top of PT</strong></td>
<td>Groups</td>
<td>Groups or families</td>
<td>Groups</td>
<td>Groups or series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 1 – Alkali Metals (AM)</td>
<td>GP1, AM – highly reactive, OX +1</td>
<td>GP 1, AM – very active, reactivity increases going down, OX +1, OSE 1, OS s1</td>
<td>GP 1, AM – silver, metals, highly reactive, reactivity increases going down, OX +1</td>
<td>GP 1 – highly reactive silver metals, OX +1, OS s</td>
<td>GP 1 – OX +1, need to lose one atom</td>
<td></td>
</tr>
<tr>
<td>GP 2 - Alkaline Earth Metals (AEM)</td>
<td>GP 2, AEM – reactive, OX +2</td>
<td>GP 2, AEM – active, OX +2, OSE 2, OS s2</td>
<td>GP 2 – active, OX +2, OS s</td>
<td>AEM</td>
<td>GP 2 – OX +2, need to lose 2 atoms</td>
<td></td>
</tr>
<tr>
<td>GP 3-5</td>
<td>GP 3-5 – mod. reactive, OX +3, +/-4, -3, OSE 3, 4, 5, OS p1, p2, p3</td>
<td>GP 3-5 – mod. active, OX +3, +/-4, -3, OS p</td>
<td>GP 3-5 – highly reactive, OX +3, +/-4, -3, OS p</td>
<td>GP 3-5 – OX +3, +/-4, -3</td>
<td>GP 3 – M &amp; NM</td>
<td></td>
</tr>
<tr>
<td>GP 6</td>
<td>GP 6 – reactive, OX –2</td>
<td>GP 6 – active, OX –2; OSE 6; OS p4</td>
<td>GP 6 – OX -2</td>
<td>GP 6 – active, OX –2, OS p</td>
<td>GP 6 – OX –2</td>
<td></td>
</tr>
<tr>
<td>GP 7 - Halogens (HA)</td>
<td>GP 7, HA - very reactive, OX -1</td>
<td>GP 7, HA – very active, OX –1; OSE 7, OS p5</td>
<td>GP 7 – reactivity increases going up, OX -1</td>
<td>GP 7 – highly reactive, OX –1, OS p</td>
<td>GP 7 – OX –1, need to gain 1 atom</td>
<td></td>
</tr>
<tr>
<td>GP 8 - Noble Gases (NG)</td>
<td>GP 8, NG – inert, not reactive, OX is 0</td>
<td>GP 8, NG – OX is 0, OSE 8, OS p6</td>
<td>GP 8, NG – OX is 0</td>
<td>GP 8 – inert, OX is 0, OS p</td>
<td>NG</td>
<td>GP 8, NG – all gases, stable, OX is 0</td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What is a group or family?”
<table>
<thead>
<tr>
<th>Properties</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers across the top of PT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groups</td>
<td></td>
<td>Groups or families</td>
<td>Groups</td>
<td></td>
<td>Groups or series</td>
<td></td>
</tr>
<tr>
<td>Group or family</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By families: AM, AEM, NG, HA, TE, LAN, ACT</td>
<td></td>
<td>Classified by the names of their groups</td>
<td></td>
<td>Organized by groups</td>
<td>By alkali, AEM, NG, inert.</td>
<td>Grouped by families</td>
</tr>
<tr>
<td>Numbers down the side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periods and Energy levels (7)</td>
<td>Series &amp; number of EL’s</td>
<td>Energy levels (7)</td>
<td></td>
<td>Energy levels</td>
<td>Series</td>
<td>Series</td>
</tr>
<tr>
<td>Period or series</td>
<td>E in a row with different phase, atomic #, atomic mass, reactivity</td>
<td>E with same # of EL’s, differ by M/NM, s or p sublevel</td>
<td>EL is a series, that differ by s or p sublevels, atomic # &amp; mass, reactivity</td>
<td>E’s in a group</td>
<td>Series goes across, has different atomic numbers</td>
<td>Goes across, represents all main block elements</td>
</tr>
<tr>
<td>Electron configuration</td>
<td>EL’s get bigger going down a GP</td>
<td>Organized by EC, s, p, d, f sublevels</td>
<td>EC depends on EL’s (7), S, p, d, f blocks</td>
<td>By EC, 7 EL; s, p, d, f blocks</td>
<td>Hydrogen is 1s</td>
<td>Organized by s, p, d, f sublevel</td>
</tr>
<tr>
<td>Atomic number</td>
<td>By atomic number in order from left to right</td>
<td>Organized by atomic number</td>
<td>Organized in order of atomic # and mass, periodicity</td>
<td>By atomic number</td>
<td>In order by atomic number</td>
<td>Organized in order by atomic number</td>
</tr>
<tr>
<td>Periodicity</td>
<td>Organized by periodicity</td>
<td>Periodicity (see cell above)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Why is PT shaped as it is?</td>
<td>Too big if f block in middle</td>
<td>Similar E are close to each other</td>
<td>Too big if f block in middle</td>
<td>EC, shape breaks up sublevel blocks</td>
<td>To separate M &amp; NM</td>
<td>Too long if 4f &amp; 5f in middle. E with same sublevel together</td>
</tr>
</tbody>
</table>

TABLE L24: COMPARISON STUDENTS’ CONCEPTIONS OF THE ELEMENTS (PTLR LEVEL 1)

<table>
<thead>
<tr>
<th>Definition of element</th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
<th>CS6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Natural &amp; manmade</td>
<td>Don’t know</td>
<td>S, L, G &amp; synthetic E’s</td>
<td>Some found in earth, some not</td>
<td>2 or more C’s bond together</td>
<td>Don’t know</td>
<td>100%</td>
</tr>
<tr>
<td>E names ID on interview list (4)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100%</td>
</tr>
<tr>
<td>E names ID in C on interview list (17)</td>
<td>100</td>
<td>76</td>
<td>35</td>
<td>59</td>
<td>35</td>
<td>0</td>
<td>51%</td>
</tr>
</tbody>
</table>


The numerical values on the table above represent percentage of elements for which students could provide accurate data.
<table>
<thead>
<tr>
<th></th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
<th>CS6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical properties *</td>
<td>S, L, G.</td>
<td>Not sure</td>
<td>Doesn’t know</td>
<td>Acids and bases</td>
<td>Doesn’t know</td>
<td>Doesn’t know</td>
</tr>
<tr>
<td>Metal/Nonmetal</td>
<td>M, NM</td>
<td>M, NM</td>
<td>M, NM, ML</td>
<td>NM</td>
<td>M, NM, ML</td>
<td></td>
</tr>
<tr>
<td>Phase</td>
<td>S, L, G</td>
<td>States - S, L, G</td>
<td>S, L, G</td>
<td>S, L, G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical Properties **</td>
<td>M are shiny and hard</td>
<td>Not sure</td>
<td>Doesn’t know</td>
<td>Doesn’t remember</td>
<td>Doesn’t know</td>
<td>Doesn’t know</td>
</tr>
<tr>
<td>Oxidation Number</td>
<td>Charges</td>
<td>Charges</td>
<td></td>
<td>Charges</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


* Student responses to the direct question, “What are some of the physical properties of the elements?”

** Student responses to the direct question, “What are some of the chemical properties of the elements?”
TABLE L26: COMPARISION STUDENT CONCEPTIONS AND EXAMPLES OF GROUPS AND FAMILIES (PTLR LEVEL 3)

<table>
<thead>
<tr>
<th>Group or family *</th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
<th>CS6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numbers across top of PT</td>
<td>Groups</td>
<td>Groups or families</td>
<td>Different groups</td>
<td>Don’t know</td>
<td>Groups</td>
<td>Doesn’t know</td>
</tr>
<tr>
<td>GP 1 – Alkali Metals (AM)</td>
<td>GP 1, AM - +1 charge</td>
<td>GP 1, Alkali metals, +1 charge</td>
<td>AM - +1 charge</td>
<td>GP 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 2 - Alkaline Earth Metals (AEM)</td>
<td>GP 2, AEM - +2 charge</td>
<td>GP 2, Alkali metals, +2 charge</td>
<td>AEM - +2 charge</td>
<td>GP 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 3-5</td>
<td>GP 3-5 – NM; +3, -4, -3 or +5 charges</td>
<td>GP 3-5, Alkaline, GP 3 is either +3 or −3 charge</td>
<td>+3, none, -1 charges</td>
<td>GP 3-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 6</td>
<td>GP 6 – NM, -2 charge</td>
<td>GP 6, Alkaline, -2 charge</td>
<td>-2 charge</td>
<td>GP 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 7</td>
<td>GP 7, NG - NM, -1 charge</td>
<td>GP 7, Alkaline</td>
<td>Row 7 – gases</td>
<td>GP 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP 8 - Noble Gases (NG)</td>
<td>GP 8 - NM</td>
<td>GP 8, Alkaline</td>
<td>Row 8 - solids</td>
<td>GP 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transition Elements</td>
<td>Transition M in middle section</td>
<td>Metalloids in middle section</td>
<td>Transition M’s in middle section</td>
<td>Transition M’s in block d</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Student responses to the direct question, “What is a group or family?”
TABLE L27: COMPARISON STUDENTS’ CONCEPTIONS OF THE ORGANIZATIONAL BASIS OF THE ELEMENTS ON THE PERIODIC TABLE (PTLR LEVEL 4)

<table>
<thead>
<tr>
<th></th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
<th>CS6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal or nonmetal</td>
<td>M or NM</td>
<td>M or NM</td>
<td>Classified by type of M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location &amp; purpose of ZZ</td>
<td>Unsure of location and purpose</td>
<td>Unsure of location Separates M, NM</td>
<td>Drew ZZ, divides M &amp; NM</td>
<td>ZZ in NM area, separates S &amp; G</td>
<td>ZZ near GP 3, divides M &amp; NM</td>
<td>Doesn’t know about ZZ</td>
</tr>
<tr>
<td>Location of M &amp; NM</td>
<td>M - GP 1 &amp; 2, TE, bottom block (f). NM are GP 3-8</td>
<td>M – Alkili, alkaline, NM – ML in middle</td>
<td>M on left of ZZ, NM on right, ML along the ZZ</td>
<td>M – AM, AEM, TE, NM (NM in p block, type of M)</td>
<td>Not sure</td>
<td></td>
</tr>
<tr>
<td>Numbers across the top of PT</td>
<td>Groups</td>
<td>Groups or families</td>
<td>Different groups</td>
<td>Don’t know</td>
<td>Groups</td>
<td>Doesn’t know</td>
</tr>
<tr>
<td>Numbers down the side</td>
<td>Periods</td>
<td>Rows</td>
<td>Rows</td>
<td>Not sure</td>
<td>Doesn’t remember</td>
<td>Doesn’t remember</td>
</tr>
<tr>
<td>Group/family or series/period</td>
<td>Separated into GP’s and periods.</td>
<td>Separated into GP’s or families</td>
<td>In different GP’s or families</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electron configuration</td>
<td>Block s is GP 3-8</td>
<td></td>
<td>Classified in blocks: p, d, f</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atomic number</td>
<td>Arranged by atomic # &amp; mass #</td>
<td>Arranged by atomic #</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td>Classified by form of matter: S, L, G.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE L28: ELEMENT SURVEY RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Symbols</th>
<th>Description *</th>
<th>Occurrence or Use *</th>
<th>Description, Occurrence or Use *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Diff</td>
<td>Pre</td>
</tr>
<tr>
<td>S1</td>
<td>80</td>
<td>90</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>S2</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>S3</td>
<td>90</td>
<td>100</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>S4</td>
<td>70</td>
<td>60</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>S5</td>
<td>90</td>
<td>80</td>
<td>-10</td>
<td>0</td>
</tr>
<tr>
<td>S6</td>
<td>50</td>
<td>70</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Sample Average</td>
<td>80</td>
<td>83</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Class Average</td>
<td>86</td>
<td>84</td>
<td>-2</td>
<td>14</td>
</tr>
</tbody>
</table>

The element survey presented ten different elements. The numerical values in the table above represent percentages of elements for which students could provide accurate data.

* Students were asked to describe what the elements looked like physically.
TABLE L29: PRE- AND POSTTEST RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Atomic Structure (2 items)</th>
<th>Properties (4 items)</th>
<th>Electron Config. (7 items)</th>
<th>Reactivity (11 items)</th>
<th>Chemical Formulas (4 items)</th>
<th>Groups (7 items)</th>
<th>Test Overall (28 items)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Diff</td>
<td>Pre</td>
<td>Post</td>
<td>Diff</td>
<td>Pre</td>
</tr>
<tr>
<td>S1</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>86</td>
</tr>
<tr>
<td>S2</td>
<td>50</td>
<td>0</td>
<td>-50</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>57</td>
</tr>
<tr>
<td>S3</td>
<td>50</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>75</td>
<td>75</td>
<td>86</td>
</tr>
<tr>
<td>S4</td>
<td>50</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>25</td>
<td>-25</td>
<td>57</td>
</tr>
<tr>
<td>S5</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>43</td>
</tr>
<tr>
<td>S6</td>
<td>0</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>75</td>
<td>25</td>
<td>57</td>
</tr>
<tr>
<td>Average</td>
<td>40</td>
<td>85</td>
<td>45</td>
<td>33</td>
<td>55</td>
<td>22</td>
<td>64</td>
</tr>
<tr>
<td>Class Average</td>
<td>55</td>
<td>80</td>
<td>25</td>
<td>25</td>
<td>48</td>
<td>23</td>
<td>51</td>
</tr>
</tbody>
</table>

Each value in the table above is the percentage of items scored correct.
TABLE L30: PTLR LEVELS OF PINE HIGH SCHOOL STUDENTS ACROSS THE UNIT STUDY

<table>
<thead>
<tr>
<th>Interview</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>5 *</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2.8</td>
</tr>
<tr>
<td>Two</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3.8</td>
</tr>
<tr>
<td>Three</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3.8</td>
</tr>
<tr>
<td>Four</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3.8</td>
</tr>
<tr>
<td>Five</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>Gain Across Unit Study</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.7</td>
</tr>
</tbody>
</table>

* Student began the interview at Level 4 and ended at Level 5.

TABLE L31: PTLR LEVELS OF EAST HIGH SCHOOL STUDENTS

<table>
<thead>
<tr>
<th>Comparison Interview</th>
<th>CS1</th>
<th>CS2</th>
<th>CS3</th>
<th>CS4</th>
<th>CS5</th>
<th>CS6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interview</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2.2</td>
</tr>
</tbody>
</table>
APPENDIX M

PERIODIC TABLE UNIT STUDY LESSON PLANS

ACTIVITY ONE: THE PICTORIAL PERIODIC TABLE

OBJECTIVES:
Understand that everything (natural and manmade) is composed of one or more of the elements on the periodic table.
Identify patterns of physical & chemical properties of the elements on the periodic table (color, phase, metal versus nonmetal, reactivity)
Understand that the elements of periodic table are organized into groups with similar physical and chemical properties.

RESOURCES:
FOR THE TEACHER:
Poster size pictorial periodic table displayed on the classroom wall.
Overheads of the periodic table with coding and labeling to identify: element phases, element colors, metal/nonmetal, group numbers.

FOR EACH GROUP OF THREE STUDENTS:
Crayola Original Markers - Classic Colors

FOR EACH STUDENT:
“Element in a Bag” activity sheet
Notebook size pictorial periodic table.
“Mapping the Elements” activity sheet
(2) plain periodic tables

ACTIVITIES:
1. Focus student attention on the poster size pictorial periodic table, and discuss with them that everything in the universe (living, nonliving, natural, manmade) is made of one or more of the 100+ elements on the periodic table, and that the study of chemistry centers around these 100+ elements. Tell students that they will now get some hands-on experience with some of the more common elements.

2. Distribute to each group of students a bag of elements and a worksheet. Review with students the different physical properties of elements (color, phase, metal or nonmetal) and the information that they are to record for each element. Have them predict which element each item represents. Instruct students not to open the Ziplock bag with the black substance. DO NOT ALLOW STUDENTS TO HANDLE THE SULFUR (yellow powder) OR THE IODINE (tincture of iodine). Personally take these elements around to allow students to record their properties.
3. After students have completed the chart, have them develop a classification system for the elements on the list which is based on the properties of these elements. Review with students the identity of each item. Have students share the classification systems that they developed. Tell students that the most basic classification system of the elements is whether an element is a metal or nonmetal. Discuss the properties of metals (shiny, mostly silver colored, mostly solids, conduct electricity) and nonmetals (colorless or colored, mostly solids or gases, do not conduct electricity).

4. Tell students that all of the elements samples are in their pure form, and that most elements do not exist in nature in a pure form, but in a compound form with other elements. Instruct students that they will now use a periodic table of pictures on learn about the properties of the many other elements, and the patterns of these properties on the periodic table.

5. Distribute to each student a notebook size pictorial periodic table, a “Mapping the Elements” activity sheet, and 2 plain versions of the periodic table. Distribute to each group of three students a set of colored markers. Review with students the directions for step 1 on the activity sheet. Particularly emphasize that students are to observe the actual photographs of the elements, and not the colored background of the element blocks. After they have completed step 1, discuss as a class their observations, listing them on the board.

6. Review the directions for steps 2. Point out to them that the gases are represented as colored bottles connected to glass spheres or as neon lights. One is represented by a radioactive symbol. After students have completed this step, review with them the pattern associated with the phases of the elements. Most of the gases are located in the top right of the periodic table. The last column is the noble gases, next to that is a sideways “L” shape of gaseous elements, and the last gas being hydrogen located in the top left of the periodic table. There are only two liquids, those being silver mercury and red-brown bromine.

7. Review the directions for steps 3 and 4. After students have completed the activity, discuss with them the following patterns of physical properties present on their pictorial periodic tables:

   Most of the elements from the left to the middle are silver solids.
   Most of the elements in the upper right are either colored or colorless.
   The zig-zag line separates metals from nonmetals. Have students label these sections of their tables accordingly.
   Most metals are silver solids that conduct electricity. One is a silver liquid.
   Nonmetals can be either colored or colorless, with half being solids and half being gases. One is a liquid. Nonmetals do not conduct electricity.
   Most of the radioactive elements are metals.

8. Discuss with students that the silver metals in the first two columns on the periodic table that are either covered with oil in beakers or enclosed in glass; are very reactive and combine with other elements to form compounds. Discuss with students the pattern that elements in the same column generally have similar physical and chemical (reactivity) characteristics, and are called
groups or families. Have students write the group numbers across the top of their periodic tables, and then review the following individual group characteristics.

Group 1 - silver metals that are very reactive.
Group 2 - silver metals that are reactive.
Group 3 - mostly silver metals that are moderately reactive.
Groups 4 & 5 - metals and nonmetals that are moderately reactive.
Group 6 - mostly nonmetals that are reactive.
Group 7 - nonmetals that are very reactive.
Group 8 - colorless gases that are unreactive.
# ELEMENTS IN A BAG WORKSHEET

<table>
<thead>
<tr>
<th>Element # or Form</th>
<th>Color</th>
<th>Phase</th>
<th>Metal/Nonmetal</th>
<th>Element Prediction (Symbol)</th>
<th>Actual Element (Symbol)</th>
<th>Actual Element (Name)</th>
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</thead>
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<tr>
<td>Element #1</td>
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</table>

Phase - solid, liquid or gas.
PICTORIAL PT ACTIVITY SHEET

Name:____________________

1. Examine the photographs of the elements on the pictorial periodic table. Record your observations, especially any patterns you see, in the space below.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

2. Using a blank version of the table, circle the symbols of the elements that are gases with a yellow marker, and the symbols of the elements that are liquids with a blue marker. The uncolored blocks will represent the elements that are solids. Title this periodic table “Phases of the Elements,” and draw a key under the title.

3. Using your set of colored markers and your other plain version of the periodic table, circle each element’s symbol with its corresponding color. Be sure to use the color of the element as it appears in the photograph, and not the background color of the element block. Use the colors of carbon (symbol C, atomic number 6) and iodine (symbol I, atomic number 53) that are illustrated on the large pictorial periodic table displayed on the classroom wall. Leave the elements in the column on the far right (He, Ne, Ar, Kr, Xe, Rn) uncolored. Place a red “x” through the blocks of elements that are radioactive. Title this periodic table “Colors of the Elements.”

4. Draw the zig-zag line displayed on the large classroom pictorial periodic table onto your periodic tables.

5. What patterns do you now see on the pictorial periodic table?

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

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OBJECTIVES:
Distinguish elements from compounds.
Identify elements and compounds in food and health products.
Identify the biological relevance of certain elements of the periodic table.
Identify which elements are likely to combine to form ionic or covalent compounds.
Understand that oxygen combines with a number of different elements to form compounds.

RESOURCES:
FOR THE TEACHER:
Overheads of the periodic table

FOR EACH GROUP OF THREE STUDENTS:
A set of products (cereal, multimineral supplement, megamineral supplement)
Crayola Original Markers - Classic Colors

FOR EACH STUDENT:
Periodic Table of the Elements for Biology
Product Analysis I activity sheets
Compound Analysis activity sheets
List of Common Elements
5 plain periodic tables

ACTIVITIES:
1. Review with students the patterns and the structure of the periodic table (solid/liquid/gas, colors, metals/nonmetals, groups) that they discovered in the last activity. Tell students that in this activity they will become familiar with the elements that are necessary for good health. Ask students to name any that they are familiar with. Record their answers on the board. Distribute to each student a Periodic Table of the Elements for Biology. Discuss with students the different color-coded categories: basic nutrient (C, H, O, N), macronutrient (4 block square of group 1 & 2 metals, and 3 block rectangle), micronutrient (most of 3d series), trace nutrient, inert element, biotoxin (most of 4f series), radioactive element (all elements after #84, including all of 5f series). Use the information on the back of the chart to discuss the relative amounts of each element needed for good health.

2. Divide students into pairs and distribute to each pair a cereal product, and distribute to each student an activity sheet. Instruct students to read the labels and identify the elements contained in each product. They should then record the elements they discover on their worksheets, along with the compound the elements is found in, if given. Before students begin, review with them the chemical composition of water, salt and carbohydrates. Also discuss with them the meaning of the -ate and -ide suffixes. (The -ate suffix means that oxygen has combined with the element. The -ide suffix means that the element is in ion form.) Circulate among the groups to assist students in identifying all of the elements in the product.
3. After students finish step 2, review their findings and address any misconceptions students may have related to the difference between elements and compounds (i.e. thiamine, vitamin A, carbohydrate are not elements). Now distribute to students a multimineral supplement and another activity sheet. Instruct students to follow the same procedure as before. Circulate among the groups to assist students in identifying all of the elements in the product.

4. After students complete both worksheets, distribute three plain forms of the periodic table and the colored markers. Explain to students that they will now map out the elements they found in each product. They will do this mapping on a plain periodic table, using a separate one for each different product they analyzed. Tell them to use the same key and color scheme that is found on the Periodic Table of the Elements for Biology, and to copy this key on each periodic table. Review with students the visual patterns among the elements associated with each nutrient color-coded categories: basic nutrient (C, H, O, N), macronutrient (4 block square of group 1 & 2 metals, and 3 block rectangle), micronutrient (most of 3d series), trace nutrient, inert element, biotoxin (most of 4f series), radioactive element (all elements after #84, including all of 5f series). Instruct students to draw neat circles around each element, in lieu of coloring the complete area of each element block, as they did in the first activity. Also distribute to students a megamineral supplement to map in addition to the cereal and multimineral supplement. After they have completed the mapping, instruct students to analyze the mapped periodic tables to compare the relative nutritional value of the three products.

5. Lead a class discussion, asking students to report any patterns they found. (The multimineral supplement had more necessary elements than the cereal, the megamineral supplement had more elements than both, but many were biotoxins, and one was radioactive.)

6. Ask students how many of the elements they identified were in an uncombined form. That is, how many were not combined with another element in a compound. (None) Discuss with students the fact that most elements combine with other elements to form compounds, and do not exist in nature in their pure elemental form. Tell students that this is because the atoms of most elements readily form chemical compounds. Ask students which group of elements did not form any compounds (noble gases). Tell students that these elements are very unreactive, and rarely form any compounds. Inform students that the next part of this activity will help them learn more about which elements combine together to form compounds.

7. Distribute to each student the compound analysis activity sheets, and two blank periodic tables. Review the instructions with students, and have them begin. After students complete the first page, review with them the following patterns related to compounds: Each of these compounds is comprised of a metal and a nonmetal. In each compound name, the metal is on the left and the nonmetal is on the right.

8. Review the directions listed on the top of the second page and have students begin. After students finish, discuss with them the following:

A metal from group 1 combined with nonmetals from group 7.
A metal from group 2 combined with a nonmetal from group 6.
Metals from the middle section combined with nonmetals in groups 6 & group 7. Metals combine with nonmetals to form ionic compounds.

9. Review the remaining directions on the second page and have students begin. After students finish, discuss with students the following:

Both metals and nonmetals combine with oxygen to form compounds. Metals often combine with oxygen to form oxides. Nonmetals often combine with oxygen to form -ates. Metals combine with nonmetals to form ionic compounds. Nonmetals combine together to form covalent compounds.
PRODUCT ANALYSIS I ACTIVITY SHEET         Name: _______________________

Product: ______________________________

List each element you found in the product, along with its symbol, and the chemical compound it is found in (if identified).

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<tr>
<th>Element</th>
<th>Symbol</th>
<th>Chemical Compound or Formula</th>
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</table>
COMMON ELEMENTS

Boron B
Bromine Br
Calcium Ca
Carbon C
Chlorine Cl
Chromium Cr
Cobalt Co
Copper Cu
Fluorine F
Hydrogen H
Iodine I
Iron Fe
Magnesium Mg
Manganese Mn
Molybdenum Mo
Nickel Ni
Nitrogen N
Oxygen O
Phosphorus P
Potassium K
Selenium Se
Silicon Si
Sodium Na
Strontium Sr
Sulfur S
Tin Sn
Titanium Ti
Vanadium V
Zinc Zn

COMMON COMPOUNDS

Water Contains Hydrogen, Oxygen - H2O
Salt Sodium Chloride - NaCl
Carbohydrate Contains Carbon, Hydrogen, Oxygen.
-ate Element combined with oxygen.
-ide Element in ion form.
The compounds listed below are in the multimineral supplement that you analyzed. In the list below, identify the metals by circling them with a grey marker, and the nonmetals by circling them with a blue marker. Draw the zig-zag line on the periodic table to assist you in distinguishing metals from nonmetals.

Magnesium Oxide
Zinc Oxide
Chromium Chloride
Potassium Chloride
Potassium Iodide

List below any patterns you notice.
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

On a blank copy of the periodic table, circle all the metals in the list in grey and the nonmetals in blue. For each compound listed, draw a line connecting the circled metal with the circled nonmetal with the blue marker. Loop the lines outward and separate them so that you will have room to write the following. On the connecting line write the name of the compound, the element symbols, and the group numbers of the two elements that are in the compound (i.e. 3 & 8).

Carefully examine your work and list any additional observations below.
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
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On your Product Analysis activity sheet for the multimineral product, identify and underline the compounds which contain oxygen. Remember that oxygen can be found in the oxide form or the “-ate” form. After this step has been completed, take a blank periodic table and a marker, and circle each of the elements that oxygen combines with to form an oxide or the “-ate” part of a compound. Circle metals with a grey marker and nonmetals with a blue marker. For the compounds with the “-ate” form, circle only the element that precedes the “-ate” suffix. Circle oxygen with a black marker. Draw a blue line connecting each of these elements to oxygen. As you did above, loop the lines outward and separate them. Also draw the zig-zag line separating metals and nonmetals. List below any observations you have about the elements that combine with oxygen.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

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ACTIVITY THREE: PRODUCT ANALYSIS II

OBJECTIVES:
Distinguish elements from compounds.
Identify the elements contained in various household products.
Identify the reactivity characteristic of each family or group of elements on the periodic table.
Identify which element groups are likely to combine to form ionic and covalent compounds.
Understand that oxygen combines with a number of different elements to form compounds.

RESOURCES:
FOR EACH GROUP OF THREE STUDENTS:
A set of household products (Element groups 1-7 and the transition elements)
Crayola Original Markers - Classic Colors

FOR EACH STUDENT:
Product Analysis II activity sheets
(3) plain periodic tables

ACTIVITIES:
1. Review with students what they have learned about the structure of the periodic table (groups) and patterns on the periodic table (metals & nonmetals, element phases, element combinations to form compounds). Tell students that they will now identify elements and compounds found in a number of common household products.

2. Divide students into groups of three or four, and distribute to each group a set of products. Distribute the Product Analysis II activity sheets to each student. Tell students that each set of products is designed to feature the elements in a particular group of the periodic table. Instruct them to find the group number on their activity sheet that corresponds to the product set that they have. Each product in the set contains one element (a few have two) from that respective element group. Instruct students to record the name of the product in the blank under the element it contains. In the other blanks to the side they should write the chemical compound the element is found in (if given), and other elements that are also present in the product.

3. Distribute to each student a Common Elements and Compounds reference sheet. Review with students the common compounds and their chemical formulas (water, carbohydrates, oxides, -ates) and also introduce the compound ammonia and the composition of air (nitrogen, oxygen, carbon dioxide, argon). Have students begin the activity.

4. After students have completed the product analysis, review briefly with them the featured element(s) in each product. Then distribute the Product Analysis Followup activity sheet, and review the directions with students. Tell them that steps seven...
and eight are very similar to the last two steps of the last activity.

5. After students have completed the activity, review their work on the followup activity, and particularly discuss the following:

Oxygen, Hydrogen, Sodium, Chlorine and Calcium appear frequently in compounds because they represent the most reactive groups of elements (Groups 1, 2, 6, 7) on the periodic table.

Group 1 & 7 elements are both **very** reactive, group 1 being metals and group 7 being nonmetals.

Group 2 & 6 elements are both reactive (less reactive than 1 & 7), group 2 being metals and group 6 being nonmetals.

Groups 3, 4, & 5 are moderately reactive.

Group 8 elements are very unreactive (inert) gases.

Oxygen is one of the most reactive nonmetals, and forms compounds with both metals and nonmetals.

Metals combine with nonmetals to form ionic compounds.

Nonmetals combine together to form covalent compounds.
PRODUCT ANALYSIS II FOLLOWUP ACTIVITY SHEET

1. Identify the seven products whose names contain part of an element name.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

2. Chemically speaking, what is the difference between the three different types of salt.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

3. How many different sodium compounds are in Dove soap? ____

4. Scan the “Other Elements” column of your worksheet and identify and rank the five elements that appeared most frequently in your analysis. Write the number of times the element appeared next to the element in the list.

1. ________________        4. ________________
2. ________________        5. ________________
3. ________________

5. Explain why these elements appear so frequently in compounds?

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

6. List the four compounds that were formed between group 1 and group 7 elements.

1. _________________________        2. _________________________
3. _________________________        4. _________________________
7. Map out these four compounds on a periodic table as you did in the previous activity. For each compound listed, circle the metal with a grey marker and the nonmetal with a blue marker, and draw a line connecting the two with the blue marker. Loop the lines outward and separate them so that you will have room to write the name of the compound, the element symbols, and the group numbers of the two elements that are in the compound (i.e. 3 & 6). Also highlight the zig-zag line separating metals and nonmetals.

8. On your Product Analysis II activity sheet, circle the compounds which have oxygen, as you did in the previous activity. Then take a blank periodic table and a marker, and circle each of the elements that oxygen combines with to form an oxide or the “-ate” part of a compound. Take a different colored marker and circle oxygen. Draw a line connecting each of these elements to oxygen. As you did above, loop the lines outward and separate them so that you will have room to write the name of the oxide compound or the “-ate” form. Also draw the zig-zag line separating metals and nonmetals.
<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>CHEMICAL COMPOUND OR FORMULA</th>
<th>OTHER ELEMENTS</th>
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</thead>
<tbody>
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<td>GROUP 1 ELEMENTS</td>
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<td>HYDROGEN</td>
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<td>GROUP 2 ELEMENTS</td>
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<td><strong>TRANSITION ELEMENTS</strong></td>
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ACTIVITY FOUR:
RECREATING THE PERIODIC TABLE MENDELEYEVIAN STYLE

OBJECTIVES:

Understand the organizational basis (periodicity) of the periodic table.
Identify the similar physical and chemical properties of the elements in each group or family.
Describe the structure of the periodic table in terms of groups or families, periods or series, and sublevel blocks.
Discover the periodic trends for the chemical properties of reactivity, atomic size, ionization energy, electron affinity and electronegativity.

MATERIALS
For the Teacher:
Chemisty At Work laserdisk

For Each Student:
Recreating the Periodic Table activity sheet
Characteristics of Individual Groups or Families activity chart
Periodic Trends Present on the Periodic Table chart

For Each Cooperative Group:
Element Set A - Elements in groups 1-8 for the first 5 periods, less H & He, but including Cs and Ba.
Element Set B - H & He, 6p, 7s sublevel blocks
Element Set C - Transition sublevel blocks
Element Set D - Rare earth sublevel blocks

(Each set is created using a pictorial periodic table)

PREPARATION
Remove or cover all visible periodic tables.

ACTIVITIES

1. Review with students the patterns (metal/nonmetal, phases, colors, reactivity) and the structure (groups) of the elements on the periodic table. Tell students that in the next activity they will attempt to reconstruct the periodic table using sets of element cards.

2. Distribute Element Set A to each pair of students, and the Recreating the Periodic Table activity sheet to each student. Have students place the elements in order of increasing atomic number. If they notice gaps in the numerical order, tell them to ignore them for the moment. Ask students to search for patterns in the order. If they discuss the background colors, direct
them to look at the actual pictures of the elements. Have students record on their activity sheets the patterns they notice.

3. On an overhead or a blackboard, display the same sequence of elements. Demonstrate to students that the elements can be grouped in sets of eight with the following characteristics:

   a. The first element of the set being a silver colored metal in a glass container;
   b. The second element being a silver metal, some of which are in glass containers;
   c. The third element is usually a silver metal;
   d. The seventh element is a nonmetal that is either colored or colorless.
   e. The eighth element is a gas.

Ask students why the group 1 elements and some of the group 2 elements are in glass containers. Review the patterns of reactivity among the different element groups.

4. Ask students how they can rearrange the sets to better see the repeating patterns (place the sets one above another). Use the calendar analogy to introduce the concept of periodicity at this point. Each element is like each day of the week. The repeating element sets are like the repeating weekly periods on the calendar, and are called periods or series. Each column on the periodic table is like a column on the calendar. All Mondays in a month have similar characteristics. Similarly, all elements in a column have similar chemical and physical properties, and are called a group or family. Review with students the similarities of the elements in each individual group. Define periodicity as follows: when the elements are listed in order of increasing atomic number, a pattern of repeating sequences (periods) of elements appears, which identify groups or families of elements with similar chemical and physical properties. Ask students to identify the metal/nonmetal boundary on their reconstructed periodic table.

5. Give students Element Set B (H & He, 6p block, 7s block) and ask them to try to incorporate them into the system they have developed. Discuss with students why Hydrogen has been included with the group 1 elements (reactivity and similar electron configuration, which will be discussed next). Then give students the 3d block from Element Set C (3d- 5d sublevel blocks) and ask them to decide where it should be placed on their periodic table. After the 3d block is correctly placed, give them the 4d and 5d blocks to place in their system. Distribute Element Set D (4f & 5f sublevel blocks) to students and ask them to add these blocks to their table. Discuss why these blocks are moved to the bottom of the periodic table.

6. Ask students why their periodic table is shaped the way it is. Review with them electron configuration, including: the number of possible energy levels, sublevels, orbitals; the number of electrons in each orbital and sublevel; and the order in which the sublevels are filled. List the elements H - Ne, and have students give the electron configuration of each element. Discuss the connection between the electron configuration of these elements and their placement on the periodic table. Then show students how electron configuration is the underlying basis for the structure of the periodic table. Include the following points in the discussion:
The outermost sublevel of an element can be determined by which group or block it is in.

- Groups 1 & 2 elements - s sublevel
- Groups 3-8 elements - p sublevel
- Transition elements - d sublevel
- Rare earth elements - f sublevel

The number of outer shell electrons of an element is equal to its group number. The outer energy level of an element never has more than eight electrons. (Explain why the 3D block is in the 4th Period.) The number of outer energy levels an element has is equal to the number of the period or series number it is in.

7. Distribute the Characteristics of Individual Groups or Families chart. Review the chart and have students begin to complete it, instructing them to stop when they get to oxidation number. When they complete the chart to that point, tell students that all elements want to have the electron configuration of a noble gas (eight outer shell electrons). Elements either gain, lose or share electrons to attain this state. Define oxidation number as the number of electrons an element either gains, loses or shares in a chemical bond. Give the oxidation number of each group, explaining the basis for it, and reviewing the periodic pattern for oxidation numbers. Review with students how the periodic pattern for oxidation numbers is used to predict chemical formulas.

8. Distribute to students the Periodic Trends Present on the Periodic Table chart. Have them complete the chart using the following resources. To illustrate the periodic trend of reactivity within a family, show and discuss the “Periodicity of Alkali Metals” and “Gas Combustibility” (H, He, N, O, Ar; N or Ar, H, He) movies on the Chemistry at Work laserdisk. Distribute a periodic table with small circles representing atomic size, and a line graph of atomic radius versus atomic number to help students visualize and record the related periodic trend. Distribute to students periodic tables with numerical values for ionization energy, electron affinity and electronegativity to help them identify the related trends. A line graph of ionization energy versus group number should also be provided.

9. As a final assessment, have students label a blank periodic table with the following information: Above each group write the: group number, family name, reactivity, outer shell electron configuration and oxidation number, periods or series numbers, sublevel blocks with their names, metal/nonmetal boundary.
RECREATING THE PERIODIC TABLE ACTIVITY SHEET

1. Record any patterns that you see in your sequence.

_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________
_____________________________________________________________________

2. Draw slash marks in the sequence below to identify any pattern you found.

Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Ge As Se Br Kr Rb Sr In Sn Sb Te I Xe Cs Ba

3. After arranging your cards sets one over another, record your arrangement below using the elements symbols listed above.
## Characteristics of Individual Groups or Families on the Periodic Table

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<thead>
<tr>
<th>Group # or Family</th>
<th>Physical Properties</th>
<th>Chemical characteristics</th>
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<tr>
<td></td>
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<td>Reactivity</td>
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<td>Group 8</td>
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Physical characteristics - color, metal/nonmetal, solid/liquid/gas
### PERIODIC TRENDS PRESENT ON THE PERIODIC TABLE

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<th>GOING ACROSS A PERIOD</th>
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<tr>
<td>Atomic size</td>
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<td>Electron affinity</td>
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<td>Electronegativity</td>
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<td>Reactivity of metals</td>
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<tr>
<td>Reactivity of nonmetals</td>
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APPENDIX N

PERIODIC TABLE RESEARCH STUDY CONCEPT MAP
APPENDIX O

PERIODIC TABLE CONCEPT MAP
VITA

Knight’s educational background includes a bachelor of science degree in petroleum engineering (May, 1985) and a master of natural science degree (August, 1996), both of which were received from Louisiana State University in Baton Rouge. His work experience includes two years as a petroleum engineer and nine years as a public high school science teacher. For the past five years, he has coordinated the K-12 science program for a small rural school district in Louisiana. There he has also written science-related funding proposals, and administered grants received from the Delta Rural Systemic Initiative and the Rural School and Community Trust.

During his years in education, Knight has been appointed to and served on the state-wide committees that developed Louisiana’s science framework and assessment documents. He also completed a term as regional representative on the Louisiana Science Teacher’s Association Board. He currently serves on the Governor’s Commission for Environmental Education, and is a member of the Rural Faculty of the Rural School and Community Trust. Knight has received teaching awards from the Baton Rouge Chapter of the American Chemical Society, Louisiana Public Broadcasting, and the Tandy Technology Scholars.