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ABSTRACT

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Analysis of Physical Science Textbooks for Conceptual Frameworks on Acids, Bases and Neutralization: Implications for Students' Conceptual Understanding

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ABSTRACT

Eight physical science textbooks were analyzed for coverage on acids, bases and neutralization. At the level of the text, clarity and coherence of statements were investigated. The conceptual framework for this topic was represented in a concept map which was used as a coding tool for tracing concepts and links present in textbooks. Cognitive demands placed by the textbooks on the reader were considered. Results indicate that although textbooks are readable, they fail in making explicit connections to important, underlying themes such as chemical change and physical properties. Cognitive demands placed on the reader include concurrent spatial and proportional reasoning. Furthermore, results suggest that conceptual frameworks which the students are exposed to in textbooks might be deficient not only in terms of content but also in terms of how content is weaved into a broader framework.

INTRODUCTION

Numerous studies indicate that students have difficulties with understanding key scientific concepts (Benson et al., 1993; Abraham et al., 1992; Ben-Zvi et al., 1987). Traditionally among physical sciences, chemistry has been the least studied area with respect to students' conceptual understanding (Pfundt and Duit, 1994). Most of the work on students' understandings, learning difficulties and misconceptions in chemistry has dealt with relatively classical examples such as the mole concept (Duncan and Johnstone, 1973), entropy (Campbell, 1980) and chemical equilibrium (Gussarsky and Gorodetsky, 1985).

In recent years, there has been a growing interest in the study of students' conceptions of various chemistry topics. As a result, the volume of research on students' conceptual reasoning, conceptual frameworks and misconceptions in chemistry has increased (Gallagher, 1987). Studies have been conducted on such topics as particles (Benson et al., 1993), acids and bases (Rose and Munby, 1991), combustion (Donnely and Welford, 1988) and stochiometry and chemical reactions (Ben-Zvi et al., 1987).

Evidence from research literature on students' conceptions in chemistry points to various patterns. In their explanations of phenomena, students tend to utilize everyday concepts more than chemistry concepts even after instruction (Ross and Munby, 1991). It has been suggested that non-intuitive nature of chemistry concepts might contribute to students' difficulties with understanding them (Zoller, 1990). Furthermore, prior knowledge and formal reasoning ability have been identified to play vital roles in students' conceptual understanding of chemistry (Chandran et al., 1987).

Students' difficulties with chemistry concepts have been attributed to various factors. It has been argued that textbooks (Abraham et al., 1992), laboratory investigations (Novak, 1990), instruction (Ross and Munby, 1991), teacher beliefs (Razali and Yager, 1994) and objectives of chemistry education (Ogden, 1975) contribute to these difficulties. Taken together, these factors point to the neccessity of further research into chemistry teaching and learning.

In this paper, I address the role of textbooks with respect to students' conceptual understanding of acids, bases and neutralization. The quality of school textbooks has concerned educators for a long time. It has been suggested that the failure of a text in assisting a reader to make connections across concepts could be the result of particular textbook features (Frederiksen, 1981). However, although textbooks have been the primary source of content in science instruction (Harmes and Yager, 1981), most studies investigating science textbooks have not gone beyond readability information (Weidler, 1984; Holliday and Braun, 1979; Shymansky and Yore, 1979). I will argue that identification of conceptual frameworks portrayed in textbooks is a critical component of textbook analysis. Here, the term *conceptual framework* denotes, within a particular domain, the set of concepts and the links between them.

It is crucial to identify conceptual frameworks presented in textbooks for several reasons. First, it is these conceptual frameworks that students are exposed to in textbooks. Students' conceptual understanding of the topic in question will be influenced by the nature of such conceptual frameworks. Second, an analysis of the structure of conceptual frameworks might be fruitful in determining which concepts and/or relationships are emphasized and which are underemphasized, and how. Improvement on specific deficiencies in coverage could thus be sought. Finally, comparison of conceptual frameworks of textbooks and students' conceptual understandings might reveal information about the presentation of conceptual frameworks that are more appropriate for effective learning.

Role of textbooks in students' conceptual understanding of chemistry

The principle source of content taught in most science classrooms is the textbook and instruction often parallels textbook formats (Harmes and Yager, 1981). It has been argued that reading textbooks alone is not sufficient for understanding science concepts. Laboratory, demonstrations and other activities should be used as part of a comprehensive approach to science concepts and these should be integrated with the text (Yore and Shymansky, 1985).

Inspection of textbooks show that many chemistry concepts are taught at different grade levels at varying levels of sophistication (Abraham et al., 1994). The use of atomic and molecular models are used to rationalize and explain most chemical phenomena. As a result, explanations based on the atomic theory are used at all grade levels. However, although chemistry concepts have atomic and molecular models at their core, students tend not to use these models when explaining chemical phenomena (deVos and Verdonk, 1987). Furthermore, these concepts and the underlying explanations have been shown to be subject to alternative conceptions (Griffith and Preston, 1992).

Most chemistry textbooks seem to present concepts in a reasonable and accurate manner from the chemist's point of view (Abraham et al., 1992). However textbook explanations of major chemistry concepts usually do not make sense to most students. Abraham and his colleagues (1992) reported that eighth-grade students in their study did not learn very well the five underlying chemistry concepts outlined in the textbook. The concepts studied included chemical change, dissolution and periouicity. Eighty-six percent of the responses to the test items indicated that these students either had no understanding or had developed specific misconceptions of these concepts. Since these concepts are central to beginning study of chemistry and they are taught at greater levels of sophistication at the high school and college levels, the situation poses a serious problem.

There is hence sufficient ground to challenge the limits of traditional textbook content as well as textbook-driven instruction. The constructivist model, which currently dominates science education research (McRobbie and Tobin, 1994), requires a shift in perspective from a passive student (to whom knowledge is imposed) to a student facilitated (by instruction, assessment, curriculum) in the learning process via negotiation of meaning. Undoubtably, our vision of *what* textbooks should be designed to do, *how* they should do it, as well as what constitutes effective methodology for textbook analysis and revision need to be reconsidered in light of our current understanding of how students process information.

Cognitive perspective on textbook analysis

Analysis of physical science and chemistry textbooks has generally focussed on vocabulary difficulty (Groves, 1995) and coverage of scientific literacy themes (Eltinge and Roberts, 1993; Chiappetta et al., 1991). There are further studies which investigated the number of pages devoted to specific science concepts in textbooks (Rillero and Rudolph, 1992) as well as the comparative topic coverage of science textbooks from different countries (Mo and Mo, 1985). Use of analogies in textbooks to assist acquitision of scientifically more valid conceptions have been investigated (Thiele, 1993). Although some studies have explored how the textbook can be used in the science classroom, they focused on readability information rather than on how the textbook can be used to develop theories, skills and classroom strategies that would promote effective science reading (Weidler, 1984).

Cognitive theoriests and reading researchers have gone beyond the traditional conception of text comprehensibility as a simple function of readablility, sentence length and vocabulary difficulty (Beck et. al, 1991; Perfetti, 1985; Rumelhart, 1980). Text features which influence text comprehension have been described by considering how readers construct cognitive representations of incoming information (Clark, 1977). Such a *cognitive perspective* yielded an understanding of reading as a complex process in which a reader constructs meaning by integrating perceptual, linguistic and conceptual information from the text with his or her own knowledge base (Bransford and Johnston, 1973).

Analysis of textbooks from a cognitive perspective has been critical for effective text revision. Readers' comprehension improved with texts revised from this perspective (Beck et. al, 1991). The domain of acids, bases and neutralization is unique for the study of textbooks from a cognitive perspective. This domain constitutes a rich and complex conceptual framework which encompasses various key aspects of chemistry: (1) acids and bases possess sets of physical and chemical properties which need to be weaved together carefully for a meaningful investigation of these chemicals; (2) neutralization involves chemical change, a central concern in chemistry that needs to be emphasized; (3) an explanation of neutralization makes reference to the atomic theory which is vital for understanding of all topics in chemistry; (4) at advanced levels, neutralization is considered in relation to other important chemistry concepts such as reaction rate and chemical equilibrium. An understanding of acids, bases and neutralization is crucial for understanding these related topics. It is critical that textbooks present this complex domain accurately and coherently, and that the reader is facilitated in constructing a meaningful cognitive representation of this domain. Studying conceptual frameworks of physical science textbooks can shed light on the sort of cognitive representations that readers would be led to construct by reading these textbooks.

A cognitive perspective not only extends the range of methodologies utilized in textbook analysis and revision but also points to how students' conceptual understanding can be assisted since this approach takes on the students' perspective in text comprehension. Here it will be useful to briefly review literature that embraces students' conceptual understanding in chemistry. This review will contextualize what we know of students' conceptual understanding and how this information can relate to learning from the textbook.

Students' conceptual understanding of chemistry

Different terms have used to describe students' understandings of a variety of science concepts. Some of these include *preconceptions* (Caramazza et al., 1981), *children's science* (Gilbert et al., 1982), *intuitive beliefs* (McCloskey, 1983), *misconceptions* (Cho et al., 1985), *alternative frameworks* (Driver and Erickson, 1983) and *students' errors* (Fisher and Lipson, 1986). Use of these terms is often dependent on the context of the development of the concept and the quality of knowledge being considered. Findings from research on children's ideas in science education have been summarized by West and Pines (1985), and Champagne, Gunstone and Klopfer (1983). Authors agree that:

1. Children have ideas and views concerning many science topics, even at a young age and before any formal education on the subject.
2. These naive descriptive and explanatory preconceptions are often different in significant ways from scientists' views, but are sensible and useful to the children who hold them.
3. Children's preconceptions often show remarkable consistency across diverse populations. They influence children's understanding of scientific conceptions presented by their teachers, who are frequently unaware of the existence of such views.
4. Preconceptions are remarkably resistant to change by traditional instructional methods. These student views may remain uninfluenced or be influenced in unexpected ways, by science teaching.

Since Piaget's model of intellectual development was first brought to the attention of chemists, most of the discussion of Piaget's work among chemists focused on the transition between the concrete operational and formal operational stages and ways in which instruction can be revised in light of this model (Sigel et al., 1981). Lawson and Renner (1975) identified two concept categories in the domain of chemistry: concrete and formal. Concrete concepts are those that can be learned from direct experience, whereas formal concepts require the learner to go beyond experience and base conclusions on logic and inferences. In their work with senior high school students, Lawson and Renner found that formal concepts could not be fully learned by concrete operational learners (those students requiring direct experience as the basis for conclusion). Cantu and Herron (1978) corroborated the Lawson and Renner results using secondary school chemistry students. Again, the concrete operational students were unable to understand the formal concepts.

Garnett and Treagust (1992) characterized two features of student learning that add support to the constructivist perspective. The first is the tendency for students to construct or generate their own meaning for language that is used in a scientific context. The second is students' tendency to overgeneralize statements and apply them too literally. However, authors consider the most significant finding of their study to be the identification of a new alternative framework that is based on the notion that an electric current only involves drifting electrons.

It has been shown that many students solve chemistry problems using only algorithmic strategies and do not understand the chemical concepts on which the problems are based (Niaz et al., 1991). Tracing students' understanding of chemistry concepts taught at different grade levels provides insight into the role reasoning ability and instructional exposure play in students' development of scientific concepts. Abraham and his colleagues (1994) carried out a cross-age study with junior high school physical science, high school chemistry and introductory college chemistry students. The concepts traced were chemical change, dissolution of a solid in water, conservation of atoms, periodicity and phase change. Differences in understanding with respect to grade level were found to be significant for the concepts of chemical change, dissolution of a solid in water, conservation of atoms and periodicity. However, few students in the college chemistry sample exhibited sound understanding of chemical change, periodicity or phase change. The use of particulate items (atoms, ions, molecules) increased across the grade levels. Furthermore, reasoning ability proved to be a significant factor in students' understanding of periodicity and conservation of atoms.

Students of chemistry often find both chemistry concepts and their symbolic representations difficult to understand. Ross and Munby (1991) showed that students hold idiosyncratic concepts not consistently coincident with those of the prescribed curriculum, and that everyday concepts are retained more than scientific concepts. Students performed best on pH and everyday-phenomena items but experienced difficulty with base and ion items and with writing and balancing chemical equations. Yarroch (1985) found that a large percentage of the students who were doing well in a high school chemistry course had a weak understanding of the meaning of the subscript in a chemical formula.

Zoller (1990) studied difficulties that students face in college freshman chemistry courses. He investigated topic areas such as the quantum model of the atom, oxidation-reduction reactions and chemical reactivity in organic chemistry. He concluded that the relatively large number of difficulties are probably due to the many abstract, non-intuitive concepts which are not interrelated logically with one another, at least not in a simple and straightforward sense. Furthermore, the author argued that the lack of a simple integrating conceptual scheme for all these complex concepts and sub-concepts, and the consequent difficulty in the use of the same approach for different cases and different systems, call for different, specifically designed teaching strategies for coping with the difficulty.

Cros and his colleagues (1986) investigated first year university students' conceptions of the constituents of matter and conceptions of acids and bases. The students were found to have a good knowledge of formal descriptions, but inadequate conceptions of concrete phenomena, such as heat being released during an acid-base reaction. The students did not appear to connect their knowledge with everyday phenomena. In a follow-up study, Cros and his colleagues (1987) found that some of the students (then in their second year) had modified their concepts so that, for example, a scientific definition for acids (and acid releases H^+) replaced the former descriptive definition (pH less than 7). However, other concepts, such as the descriptive definition used for pH, had hardly changed. Furthermore, introduction of Lewis generalizations which combines acidity, basicity, electrophilicity and nucleophilicity within a broad integrated scheme opens a new set of difficulties (Zoller, 1990).

Implications of this brief survey are many. Here I will limit my discussion to the role of textbooks in students' conceptual understanding. Since students hold particular conceptions that are often different from those of scientists and are resistant to change even after instruction, more effort should be placed on facilitating students in understanding the precise nature of chemistry concepts and how these concepts interrelate. One way of achieving this goal is to investigate content of textbooks and revise, if necessary, in light of how students can be scaffolded in constructing a more accurate and meaningful cognitive representation of the domain in question. In the following study, I specify a useful methodology towards identifying conceptual frameworks that students encounter in textbooks.

STUDY

The topic acids, bases and neutralization offers a unique area for studying, from a cognitive perspective, conceptual frameworks presented in textbooks for several reasons: first, it involves acids and bases with which physical and chemical properties of substances are associated. These properties are a critical component of chemistry; second, neutralization involves chemical change, a central process in chemistry; third, an explanation of neutralization integrates concepts of atomic theory (atoms, molecules, ions) which are fundamental to chemistry; fourth, at advanced levels, neutralization is considered in relation to other important chemistry topics such as heat, reaction rate, dissolution and chemical equilibrium. A basic understanding of acids, bases and neutralization is crucial for understanding these related topics. Finally, because this topic embraces various crucial aspects of chemistry via complex interconnections, it is vital that textbook readers are assisted effectively in their construction of its conceptual framework

Acids, bases and neutralization

There are two fundamental themes which characterize the study of chemistry in general. These have to do with physical properties of matter (which have empirical content) and chemical change (which is a theoretical construct). Chemical change at the level of molecules is inferred from physical properties (such as density, weight and color) and other manifested patterns (such as those in ultra-violet absorption spectra corresponding to particular functional groups in molecules) which can be captured via instrumentation. It is such patterns in the properties of matter, including those of acids and bases, that a model of chemical change can be constructed. Explanations which complement such models are based on the atomic theory.

In the case of acids and bases considered reacting with one other, the chemical change involves neutralization. Hydronium (H_3O^+) ions which are produced when acids dissolve in water and hydroxyl (OH^-) ions which are released into solution when bases react with water, react to produce water. The outcome is that of a neutral solution, which means that the solution no longer retains its acidic or basic properties. (Hence, corrosive nature of, for example, HCl, is lost when it completely reacts with a base such as NaOH. The result is a solution of NaCl, solution of table salt, which is not corrosive). These physical as well as chemical properties are imparted by the presence of the mentioned ions, regardless of what kind acid or base is in question.

Acidity concerns the amount of hydronium (H_3O^+) ions that are present in the aqueous solution. However, many textbooks relate acidity to the presence of hydrogen (H^+) ions which reflects an earlier conception in the history of chemistry. There is now evidence for the unstable nature of hydrogen (H^+) ions, which readily react in solution with water to form the hydronium (H_3O^+) ions. Yet, discussion of acidity by reference to hydrogen ions is still a useful one and is central in coverage of acids and bases in chemistry instruction today. The extent to which an acid dissociates in solution determines its strength. The amount of hydronium ions (hence an index of acidity) in a solution can be quantified with the pH scale which is a logarithmic measure of hydronium ion concentration.

Apart from these general themes, acids and bases are often considered with respect to their chemical synthesis which exemplify types of chemical reactions.

Chemical reactions (such as displacement reactions and reactions of metals with water) are important considerations in the study of matter. They show regularities as well as differences which can be traced in an effort to determine the structure and function of atoms and molecules. Synthesis of acids and bases is important industrially. Finally, since acids and bases involve ionic solutions (and neutralization involves reduction in ion concentration), they can be considered within the context of electrical conductivity.

Understanding acids, bases and neutralization

Understanding of acids, bases and neutralization involves an appreciation of a number of concepts in a network of relations (for instance, those among pH, neutralization and chemical change). Furthermore, the atomic structure of hydronium and hydroxyl ions as well as their spatial attributes with respect to each other are critical in building a model of neutralization. This means that the students need to have had a thourough grasp of the atomic theory before they can have a deep understanding of acids and bases. Along these lines, they need to be aware of some chemistry conventions such as naming and representation of atoms and molecules. Some knowledge of the Periodic Table (of elements such as H, C, O, S, Na and Cl) is necessary. Neutralization occurs with particular amounts of acids and bases, in certain proportions and therefore a quantitative investigation forms the basis for an explanation of neutralization.

The number of concepts as well as the complex set of links by which they are related to each other point to the importance of facilitating students in their learning of acids, bases and neutralization. Textbooks in particular need to acknowledge the cognitive demands placed on the reader and learner within the context of this topic.

DATA SOURCE

TEXTBOOKS

Eight physical science textbooks have been analyzed in this study. Chapter or section content of each textbook is summarized in **Appendix 1** and the names of textbooks are listed below:

Textbook No. 1 - Keifer, D. R. (1991). Exploring Matter and Energy: Physical Science. Englewood Cliffs: Globe Book Company.

Textbook No. 2 - Lamb, W. G., Cuevas, M. M., & Lehrman, R. L. (1989). Physical Science, Harcourt Brace Jovanovich, Inc.

Textbook No. 3 - Heimler, C. H. & Price, J. (1987). Focus on Physical Science. Teacher Annotated Edition. Columbus: Merrill Publishing Company

Textbook No. 4 - Boeschen, J.A., Gerard, J. A., & Storin, D. A. (1983). Foundations: Physical Science. Teacher's Annotated Edition. Coronado Publishers.

Textbook No. 5 - Hill, F.F. & Barcaski, P.B. (1974). Spaceship Earth, Physical Science. Teacher's Edition. Boston: Houghton Mifflin Company.

Textbook No. 6 - Bickel, C.L., Eigenfeld, N. D. & Hogg, J. C. (1973). Physical Science Investigations. Boston: Houghton Mifflin Company.

Textbook No. 7 - Abraham, N., Balch, P., Chaney, D. & Rohrbaugh, L.M. (1973). Interaction of Matter and Energy: Inquiry in Physical Science. Chicago: Rand McNally and Company.

Textbook No. 8 - Carter, J. L., Bajema, P. M., Heck, R. W., & Lucero, P. L. (1971). Physical Science: A Problem Solving Approach. Teachers' Edition with Annotations. Boston: Ginn and Company.

These textbooks were selected at random. Textbooks No. 1-4 were obtained from the Computer and Curriculum Inquiry Center at University of Pittsburgh and Textbooks No. 5-8 were obtained from the Curriculum Laboratory in the Education Library at Vanderbilt University. The former institution owned a set of relatively new textbooks as well as a database record of textbook use in area schools. The latter institution did not have either of these resources. The textbooks obtained from the latter institution were published in the 1970s.

None of the authors indicated a specific grade level for which their textbook was intended but all of them made indirect reference to secondary science education issues and how their textbooks relate to these issues. For example (boldface added for clarity by author of this paper):

> "Of additional sigfnificance is the fact that Interaction of Matter and Energy was designed specifically to articulate with the new **secondary school science programs** which have been developed recently with deferal support and are being used very extensively." (Textbook No. 7, p.vii)

Database search at the Computer and Curriculum Inquiry Center showed that during the 1994-1995 academic year, Textbook No. 3 was being used at various grade levels in the school districts summarized in **Table 1.** below:

Table 1. Textbook use in school districts in Western Pennsylvania.

District	Grade Textbook No. 3 used
Beaver Area	Grade 8
Apollo Ridge	Grade 7
Wester Beaver	Grades 10, 11 and 12
Hampton Township	Grade 8

The wide range of grade levels for textbook use might be intentional as suggested by the authors of Textbook No. 5 (boldface added for clarity by author of this paper):

> "**Wide Readership**: The reading level (7th grade with technical terms, 4th grade without technical terms), informal style, extensive illustration, and the numerous hands-on activities make the program ideal for average and below average students, particularly those not attuned to science." (Textbook No. 5, cover page)

TEXTBOOK FEATURES

ORGANIZATION OF TOPICS

The authors indicated or implied a purposeful sequence for organization and coverage of topics in the textbooks. For example, the author of Textbook No. 1 traces the intended purpose for each chapter from the beginning to end:

> "Section One [of Teacher's Resource Manual] provides chapter-by-chapter teaching suggestions. Section Two offers supplemental material designed to reinforce and/or expand on skills and concepts introduced in the program. The Final Competency Test may be used as the year-end cumulative review or final examination." (Textbook No. 1, p.vi)

Likewise, authors of Textbook No. 4 indicated a purpose for the sequence of topics in the textbook:

> "[E]ach lesson prepares for the next" (Textbook No. 4, p.T-2)

For all authors, the sequence of coverage of topics is justified by the nature of content. It is argued that: (1) topics with "concrete" underpinnings are to be presented prior to those with "abstract" nature; or (2) "complex" topics follow "simple" topics (boldface added for clarity by author of this paper):

> "The general organization of Physical Science proceeds from the simple to the complex. Chapter 1, for example, sets the stage for later discussions by explaining a scientific method and clearly defining often misused terms such as theory and law. Chapter 2 deals with the fundamental properties of matter. This chapter lays the groundwork for understanding how matter and energy interact. Physical Science **presents the concrete before the abstract**. Accordingly, Unit 2 begins the study of force, acceleration, speed, simple machines, work and energy. Unit 3 begins the more abstract idea of wave theory." (Textbook No. 2, p. T-10)
>
> "This text provides an adequate balance between basic physics and chemistry principles. Unit 1 covers basic principles of measurement. Motion is placed in this unit so that students **begin the course with familiar and concrete topics**. Unit 2 begins the ten-chapter study of matter. At this time, students must begin to conceptualize **abstract** information..." (Textbook No. 3, p. 16T)
>
> "Instructed learning (Jerome Bruner's phrase) is learning planned by a teacher for learners at a particular stage in their development. Further, instructed learning is planned, carefully planned to be sure, and is *intended* to meet an objective." (Textbook No. 4, p.T-2)
>
> "*Interaction of Matter and Energy* proceeds **from the simple to the complex**; it develops a science of investigation and curiosity in the student." (Textbook No. 7, p.vii)

The authors provide no reference to theoretical or empirical grounds for why such an organization is justified on the basis of cognitive development of the learner. The assumption is that the direction in development from the concrete to the abstract *is* the case and hence the textbook is justified in being parallel to it.

The topics which were identified by the author of this paper as being crucial and prerequisite to a sound conceptual understanding of acids, bases and neutralization were traced in each textbook. These topics are embraced within the discussion on the nature of acids, bases and neutralization discussed earlier in the paper. **Table 2.** illustrates the coverage of each of these topics. Except for Textbook No. 1 and Textbook No. 4, all textbooks deal with the mentioned topics prior to acids, bases and neutralization. Textbook No. 1 covers the topic of solubility right after the discussion on acids, bases and neutralization. Textbook No. 4 does not mention chemical change as a topic in itself, although it implies it via the topic of chemical reactions.

LEARNING OBJECTIVES

All authors identified improvement of critical thinking skills as well as importance of practical experience as part of objectives of science learning (boldface added for clarity by author of this paper):

> "To stimulate active learning through hands-on experiences" / "To promote science literacy through practical application of science process skills" / "To foster and **enhance critical thinking** and problem solving to aid in comprehension of key science concepts" (Textbook No. 1, p.T-vi)
>
> "Physical Science provides coverage on all phases of physical science including physics, chemistry and conservation topics. Physical Science emphasizes **thinking skills**, an appreciation of technology and practical applications of scientific principles." (Textbook No. 2, p. T-11)
>
> "Careful attention has been given to readability in an effort to **promote comprehension, student interest and student involvement in science.** The text is designed to help students **think critically** and preceive **relationships** among ideas as well as build on previous knowledge." (Textbook No. 3, p.16T)
>
> "In these investigations, students are given the opportunity to do problems (**problem-doing**, not problem-solving)." /" The abilities and capacities of the students are brought to bear in **increasingly more difficult** problem-doing and problem-solving " / "Students are encouraged to do an investigation for which they are required to design **their own mode** of inquiry." (Textbook No. 4, p. T-4)

Table 2. Topic coverage prior to acids, bases and neutralization*

Textbook /Topic	Textbook No. 1	Textbook No. 2	Textbook No. 3	Textbook No. 4	Textbook No. 5	Textbook No. 6	Textbook No. 7	Textbook No. 8
Atomic theory	Y	Y	Y	Y	Y	Y	Y	Y
Solubility	N	Y	Y	Y	Y	Y	Y	N
Concentration	Y	Y	Y	Y	Y	N#	N#	Y
Physical properties	Y	Y	Y	Y	N#	Y	Y	Y
Chemical change	Y	Y	Y	N	Y	Y	Y	Y
Chemical reactions	Y	Y	Y	Y	Y	Y	Y	N
Chemical formulas	Y	Y	Y	Y	Y	Y	Y	Y
Periodic Table	Y	Y	Y	Y	Y	Y	Y	N#

* Y indicates the mentioned topic was covered; N indicates the mentioned topic was not covered; #N indicates topic was not covered at all in that textbook

It is interesting to note that this emphasis on *critical thinking* is less explicit in the textbooks from the 1970s. The authors of the textbooks from the 1970s placed more emphasis on *experimentation* and adherence to the *scientific method* as learning goals:

> "**Why not apply this experimental method to the learning of science?** Learning from experiments is slower than learning facts by listening to leactures. But learning a lot of facts is not the most important thing you can do in school. By doing experiments you will really understand the basic concepts of physical science. /.../ When you do experiments, you will learn skills. In seeking an answer to a problem, you will work and think independently. Two of the most important skills you can have, not just in science but in all parts of your life, are the **ability to make accurate observations** and the **ability to make reasonable conclusions from your observations**." (Textbook No. 6, Preface, p.v)

> "Most of your class time will be spent in laboratory sessions: conducting investigations, collecting and interpreting data, and arriving at conclusions that are entirely your own. In other words, most of the time you will be carrying out some kind of physical science investigations rather than just reading about it or listening to your teacher tell you about experiments and investigations that someone else did. **You will be acting much like a scientist.**/.../ From your notes, you should be able to interpret the results of an investigation and to predict what should happen if you carried out another investigation in a certain way. Scientists call such predictions hypotheses. **Forming hypotheses and testing them in the laboratory (and sometimes at home) are among the many scientific skills you will use.**" (Textbook No. 7, p.viii-ix, Preface to the Student)

> "It is the hope of the authors that by the end of this course each student will have: 1. gained a **better understanding, through the discovery method, of physical and natural laws and concepts**; 2. come to appreciate the need to make accurate observations; 3. learned to keep neat, well-organized records; 4. **learned to distinguish between observations and interpretations**; 5. come to appreciate the importance of science and technology in today's world." (Textbook No. 8, p.iii-iv, Preface)

DISCUSSION ON ACIDS, BASES AND NEUTRALIZATION

The coverage of acids, bases and neutralization in the mentioned textbooks are summarized in **Table 3.** The number of pages of content excluding preface, glossary, index and appendices ranged from 325 to 613 and the coverage of acids, bases and neutralization accounted for 1.3 - 6.2 % of the total number of pages. Structure of sections on the discussion of acids, bases and neutralization in each textbook is summarized in **Appendix 2**. Textbooks 1, 2, 3, 5, 7 and 8 follow the "acid-base-pH-neutralization" sequence in that order and are fairly similar in their approach in terms of defining, describing and exemplifying the topic. Textbook No. 4 discusses acids and bases within the context of ionic compounds and chemical reactions and Textbook No. 6 covers acids with respect to their reactions with metals and their occurence in voltaic cells, as compared to the other six textbooks which devote entire sections to acids, bases and neutralization.

Discussion of acids and bases in all textbooks was based on Arrhenius definition which is useful within the context of aqueous solutions. The Bronsted-Lowry definitions which are more general and do not require that water be solvent are not mentioned.

Table 3. Summary of textbook coverage on acids, bases and neutralization

Title of textbook	Author(s)	Year of publication	Publisher	Total no. of pages*	No. of pages (acids, bases, neutralization)	% pages on acids, bases, neutralization
Exploring Matter and Energy Physical Science	Kiefer, D R	1991	Globe Book Company	450	7	1 6
Physical Science	Lamb, W. G., Cuevas, M. M Lehrman, R. L	[illegible]	Harcourt B. Jovanovich Publishers	613	20	3 3
[illegible] Physical Science	Heimler, C H, Price, J	1987	Merrill Publishing Company	555	23	4.1
[illegible] Physical Science	Boeschen, J. A., Gerard, J A., Storin, D. J	1983	Coronado Publishers	325	4	1.3
[illegible] Earth Physical Science	Hill, F F., Barcasku, P B.	1974	Houghton Mifflin Company	433	27	6.2
[illegible]	[illegible], C L., Eigenfeld, N D Hogg, J C.	1973	Houghton Mifflin Company	351	12	3 4
[illegible] of Matter and Energy [illegible] Physical Science	Abraham, N., Balch, P., Chaney, D., Rohrbaugh, L.M.	1973	Rand McNally and Company	341	8	2 3
Physical Science A problem Solving Approach	Carter, J. L., Bajema, P M., Heck, R W., & Lucero, P L.	1971	Ginn and Company	433	22	5.1

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* [illegible] description, appendices, glossary and index

METHODOLOGY

UNIT OF ANALYSIS AND ANALYSIS CRITERIA

Unit of analysis was the sentences in the text on acids, bases and neutralization. Only the text on content was considered in this study. That is, the text accompanying application of this content in suggested experimental procedures (which often followed the core content) was not taken into consideration. Chemical formulas representing reactions were noted but were not taken to count as "sentences." The primary focus was on the text. The formulas were considered when they elaborated on or complemented the text. Overall, the textbooks presented accurate accounts of acids, bases and neutralization. At the level of the sentences, the criteria of clarity and coherence were employed to assess whether particular links between concepts were made.

Clarity

The criterion of *clarity* describes grammatically correct and logically sound sentences in a textbook. Overall, all textbooks analyzed in this study contained short and straightforward sentences which were often descriptive and factual:

> "Acids are corrosive. This means they can react with and dissolve away most materials." (Textbook No. 1, p.155)
>
> "The pH paper is used to determine if a solution is acidic, basic or neutral." (Textbook No. 2, p.474)
>
> "Bases usually taste bitter and feel slippery. However, taste and touch are not safe methods to identify a base" (Textbook No. 3, p.306)
>
> "In every neutralization reaction, an acid and a base react to form a salt and water." (Textbook No. 4, p. 58)

"It was pointed out in the list of properties of acids and bases that litmus solution changes to a particular color in the presnnce of an acid or a base" (Textbook No. 8, p.373).

"The strength of an acid depends on how freely it forms ions or ionizes in water" (Textbook No. 5, p.374)

Coherence

Coherence refers to logical connections and consistency between sentences in sequence. Difference was noted both within and across textbooks with regard to their coherence. At certain sections of the textbooks, sentences were coherent:

"All acids contain hydrogen. More exactly, an acid is any compound that contains hydrogen and releases hydrogen ions when the acid is dissolved in water." (Textbook No.1, p.155)

Other sections were incoherent. For instance, the introduction to acids in Textbook No. 5 begins with the following statements:

"All the substances listed below are acids [examples]. Most people think that all acids are dangerous. This is not true. Many acids are dangerous but many acids are not." (Textbook No. 5, p. 371)

No direct definition of an acid follows this introduction. Often, sentences were rather definite and distinct with respect to what they expressed without much emphasis on the sequence in which they occurred. For instance, in the following example, the sentences could have been in any sequence. That is, the sequence of sentences does not add up to a coherent sum as to the significance of this information and how this information holds together:

"Sodium hydroxide and other hydroxides are known as bases. A base has the hydroxide ion written at the end of its formula. It is called a base whether or not it is in water solution. Bases are compounds that contain the hyd.oxide ion and turn pink litmus blue." (Textbook No. 4, p.41)

In short, it was not possible to assign coherence or incoherence to the entirety of any of the textbooks.

CODING SCHEME FOR CONCEPTUAL FRAMEWORKS

Concept maps

Each textbook was traced with respect to its conceptual framework on acids, bases and neutralization. Concept maps were used as coding tools. This approach to coding and comparison of semantic nets on concepts has been undertaken in various domains (Erduran and Duschl, 1995; Leinhardt and Smith, 1985) and is an extension of conventional use of concept maps in students' learning (Schreiber and Abegg, 1991; Novak and Gowin, 1984). A concept map (**Figures 1 a, b and c**) was constructed based on the author's expertise in chemistry. This concept map was considered with respect to three domains: domain A consists of the main concepts and links which concern acids; domain B consists of the main concepts and links which concern bases; domain C consists of those concepts which are common to both acids *and* bases. However, it should be noted that the presented concepts and links are not exhaustive. For instance, more links can be established between concepts (e.g. chemical change and ions are related). This framework however provides a useful means of laying a rather comprehensive map on acids, bases and neutralization.

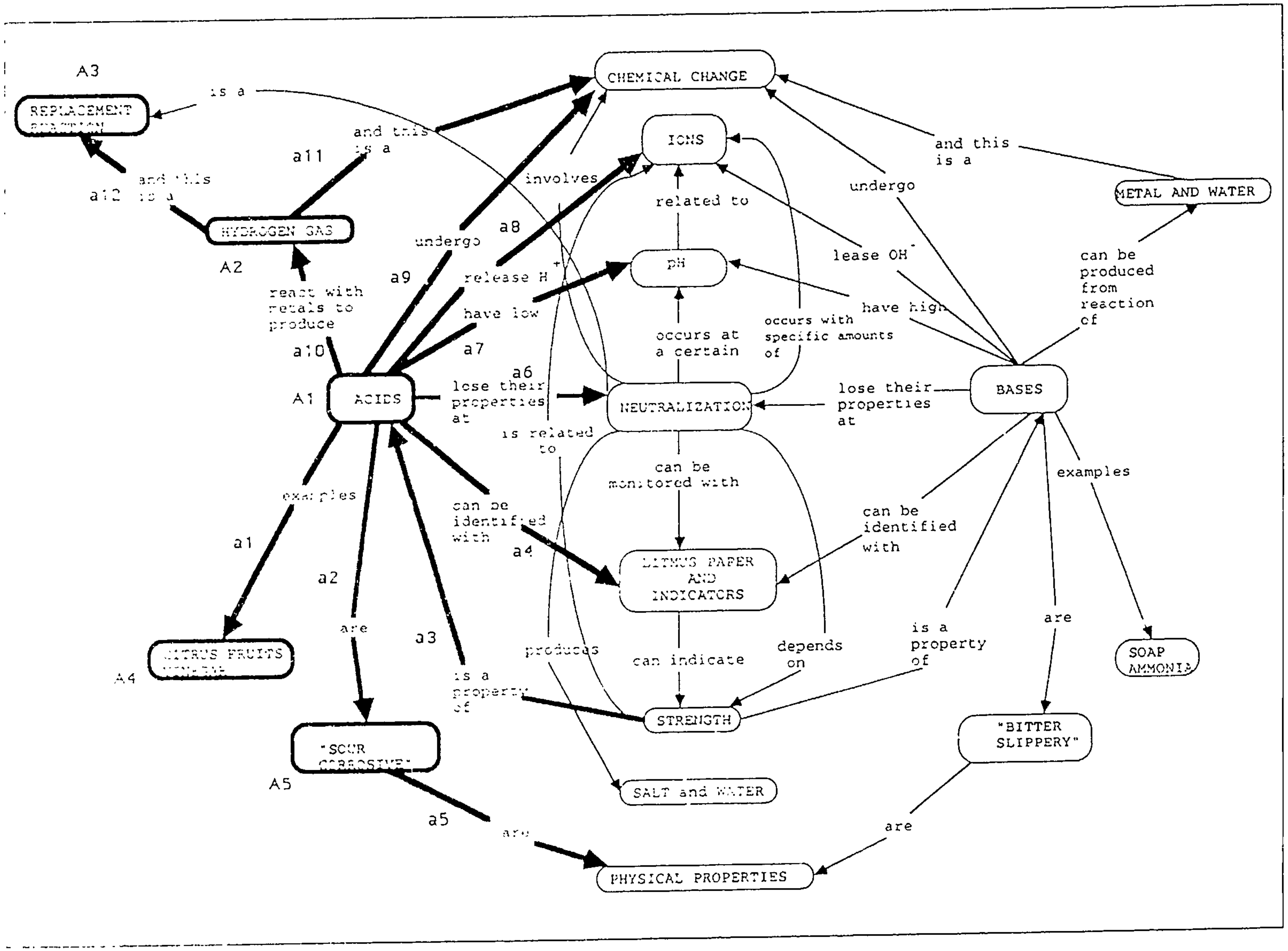

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Figure 1a. Domain A: Concepts and links about acids

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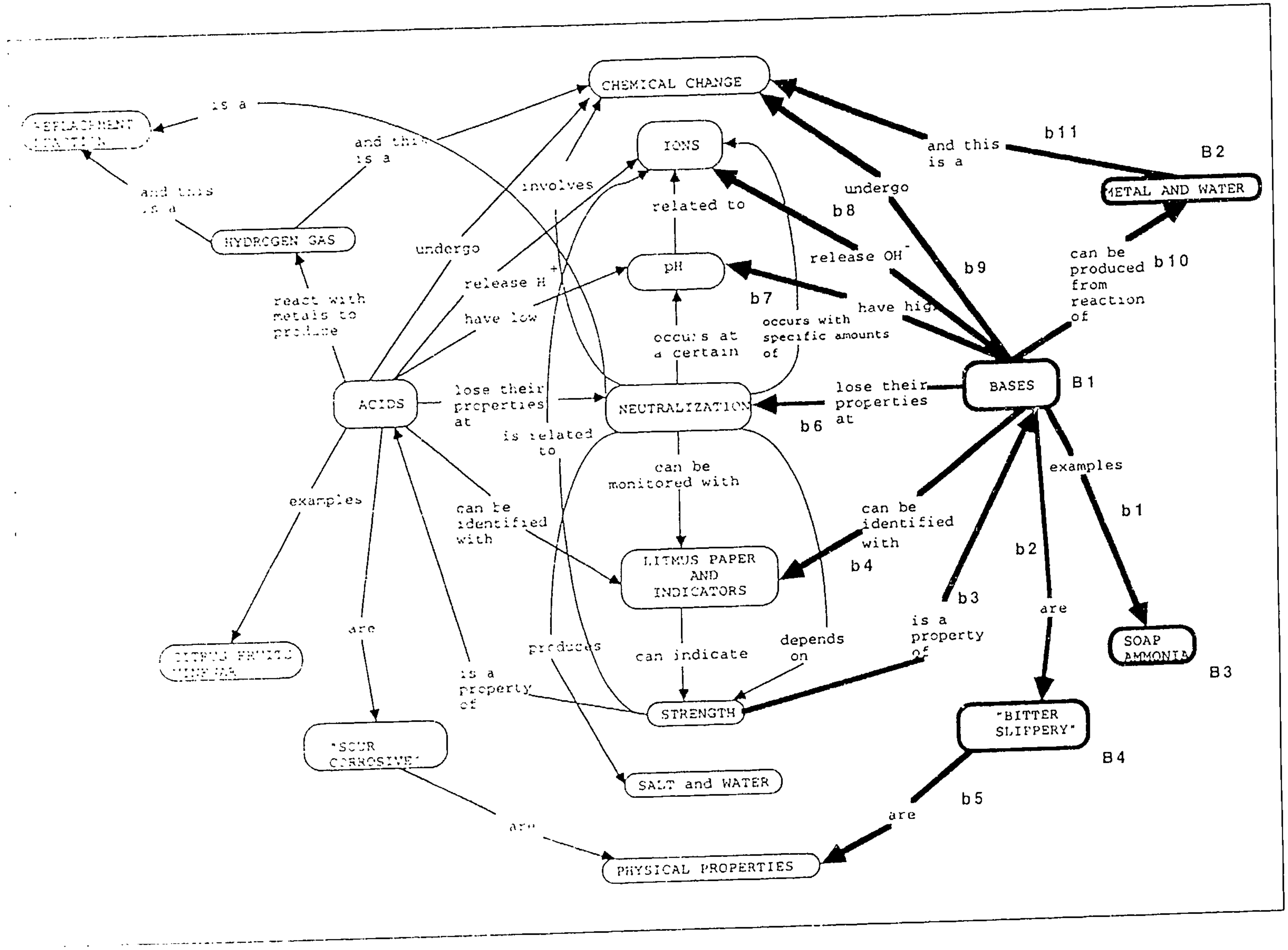

Figure 1b. Domain B: Concepts and links about bases

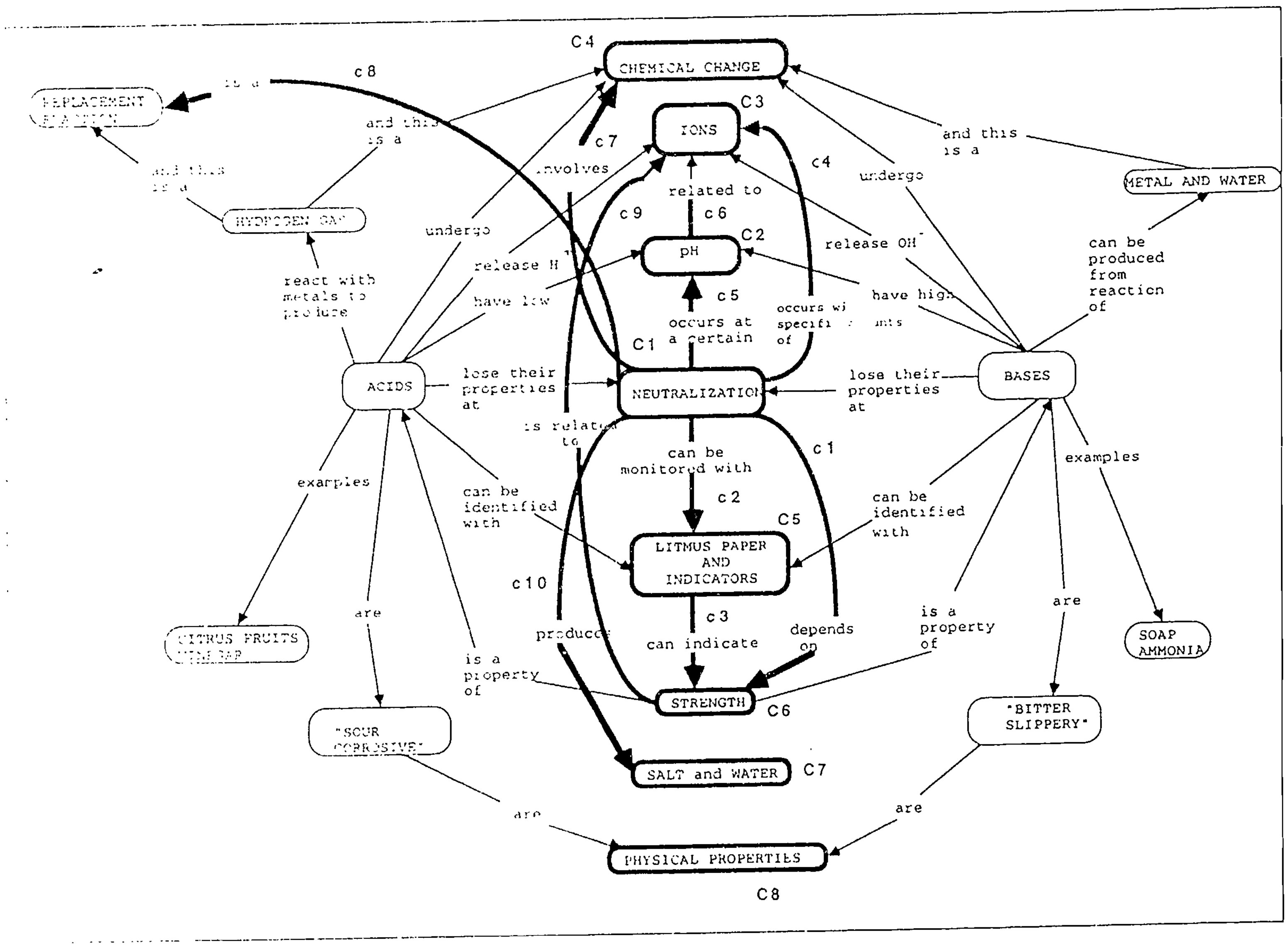

Figure 1c. Domain C: Concepts and links about acids and bases

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Coding

Coding was done by checking off, on the concept map, the concepts as well as the links between these concepts mentioned in the textbooks. Most of the sentences in all the textbooks were straightforward which did not demand interpretation and judgment. Hence, interrater-reliability was not considered to be of high relevance in this study. **Figures 2-9.** illustrate the concept maps tracing conceptual frameworks from each textbook. Highlighted parts of these concept maps display the presence or absence of particular concepts and links. In Textbooks Nos. 1, 2, 3, 5, 7, 8 highlighted parts indicate absence of those concepts and links. In Textbooks Nos. 4 and 6 highlighted parts indicate presence of those concepts and links. Textbooks No. 4 and 6' s coverage of acids, bases and neutralization was minimal in that this topic was considered within the context of another topic (chemical reactions), that is, not as a main topic by itself. The number of concepts and links mentioned in these textbooks were hence fewer than those mentioned in textbooks where acids and bases occupied a chapter.

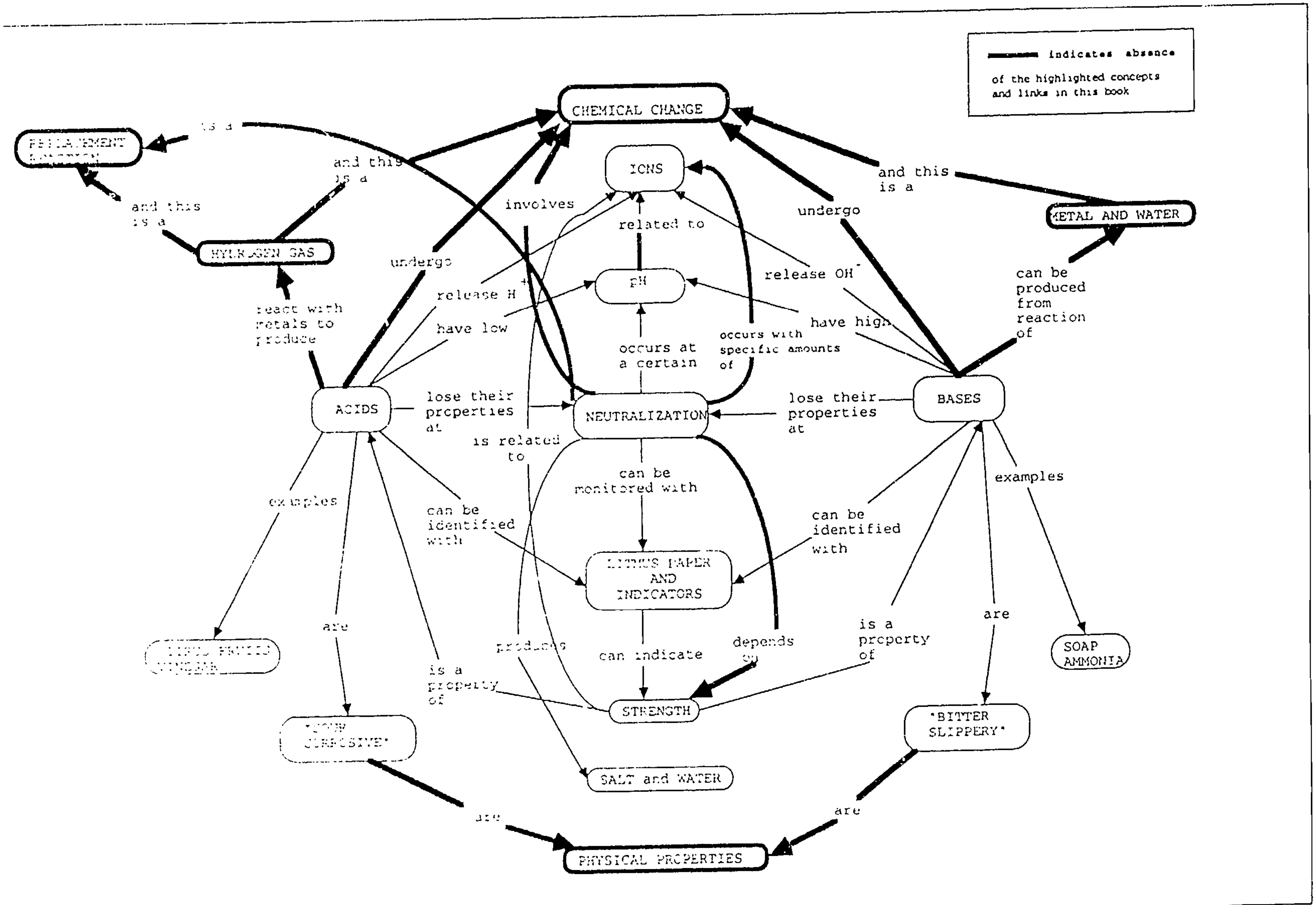

Figure 2. Conceptual framework of Textbook No. 1

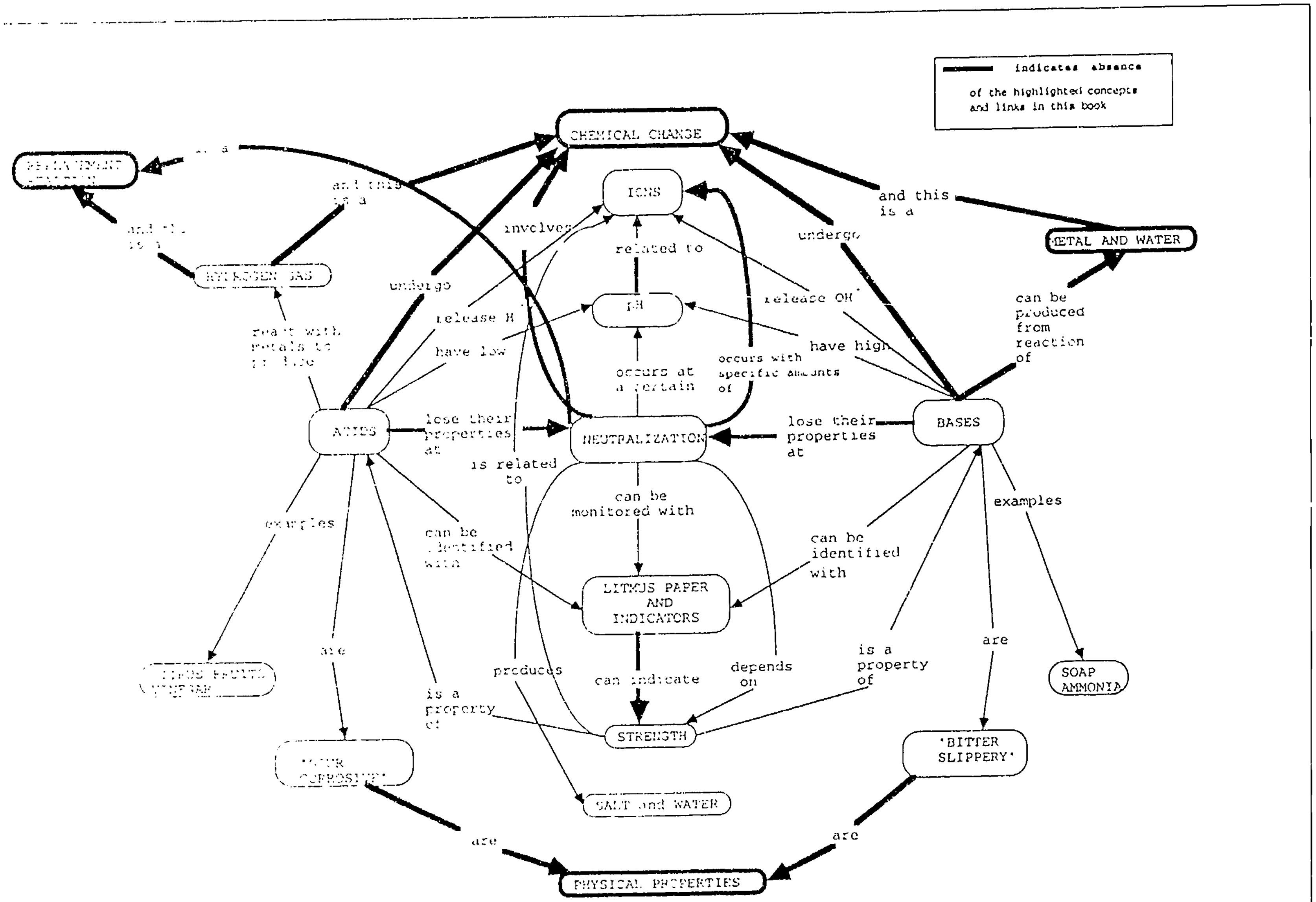

Figure 3. Conceptual framework of Textbook No 2

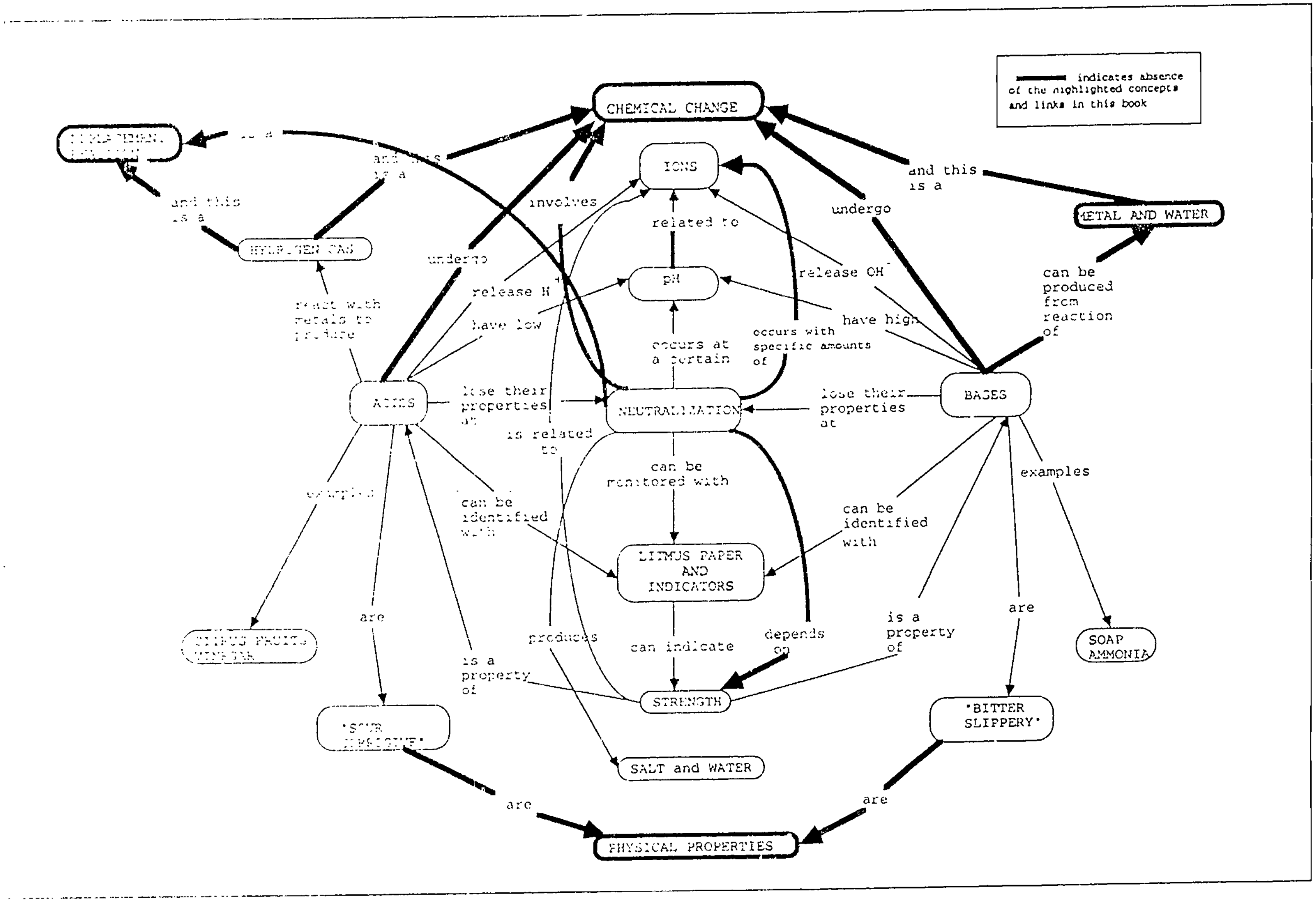

Figure 4. Conceptual framework of Textbook No 3

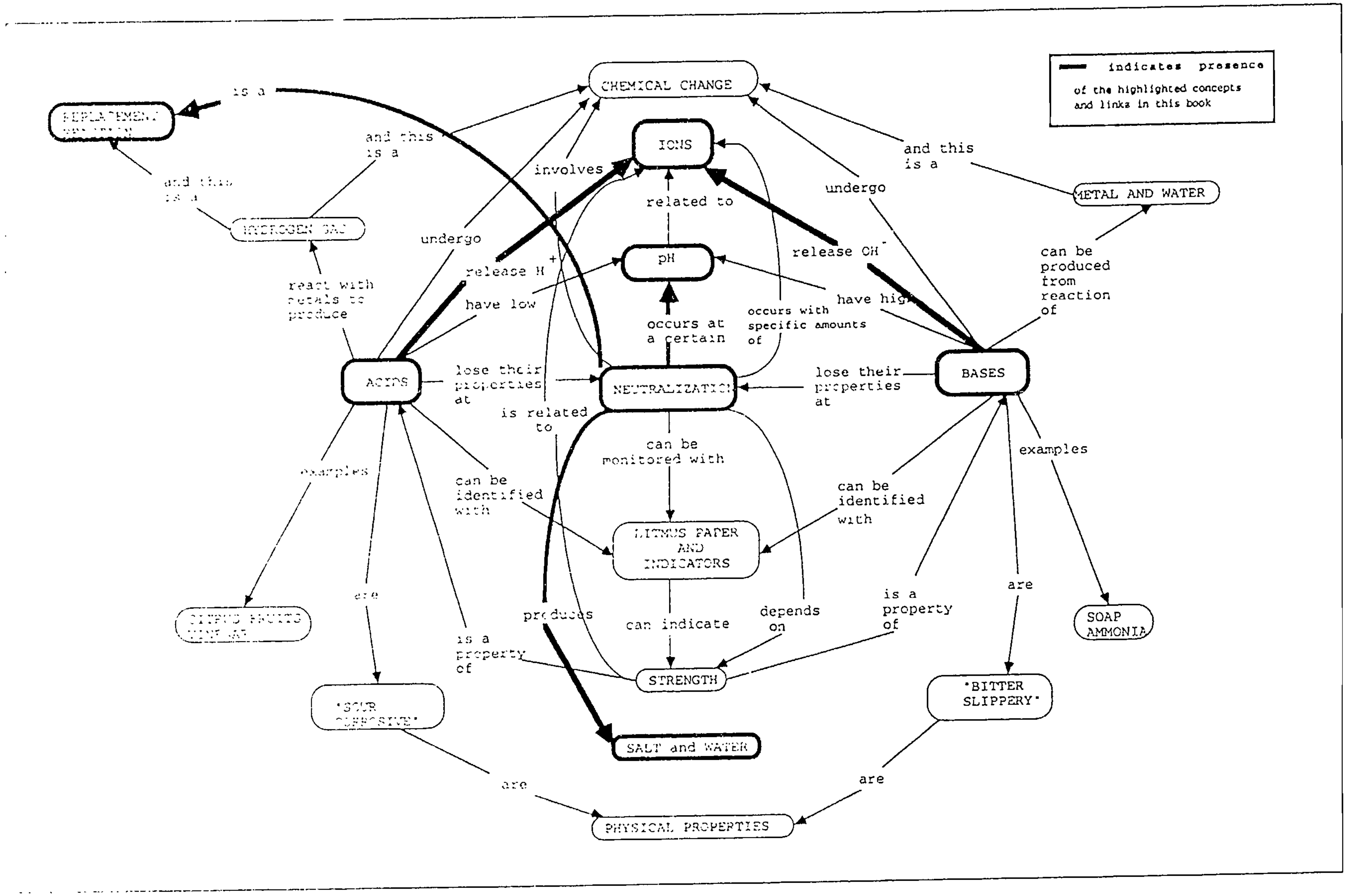

Figure 5. Conceptual framework of Textbook No. 4

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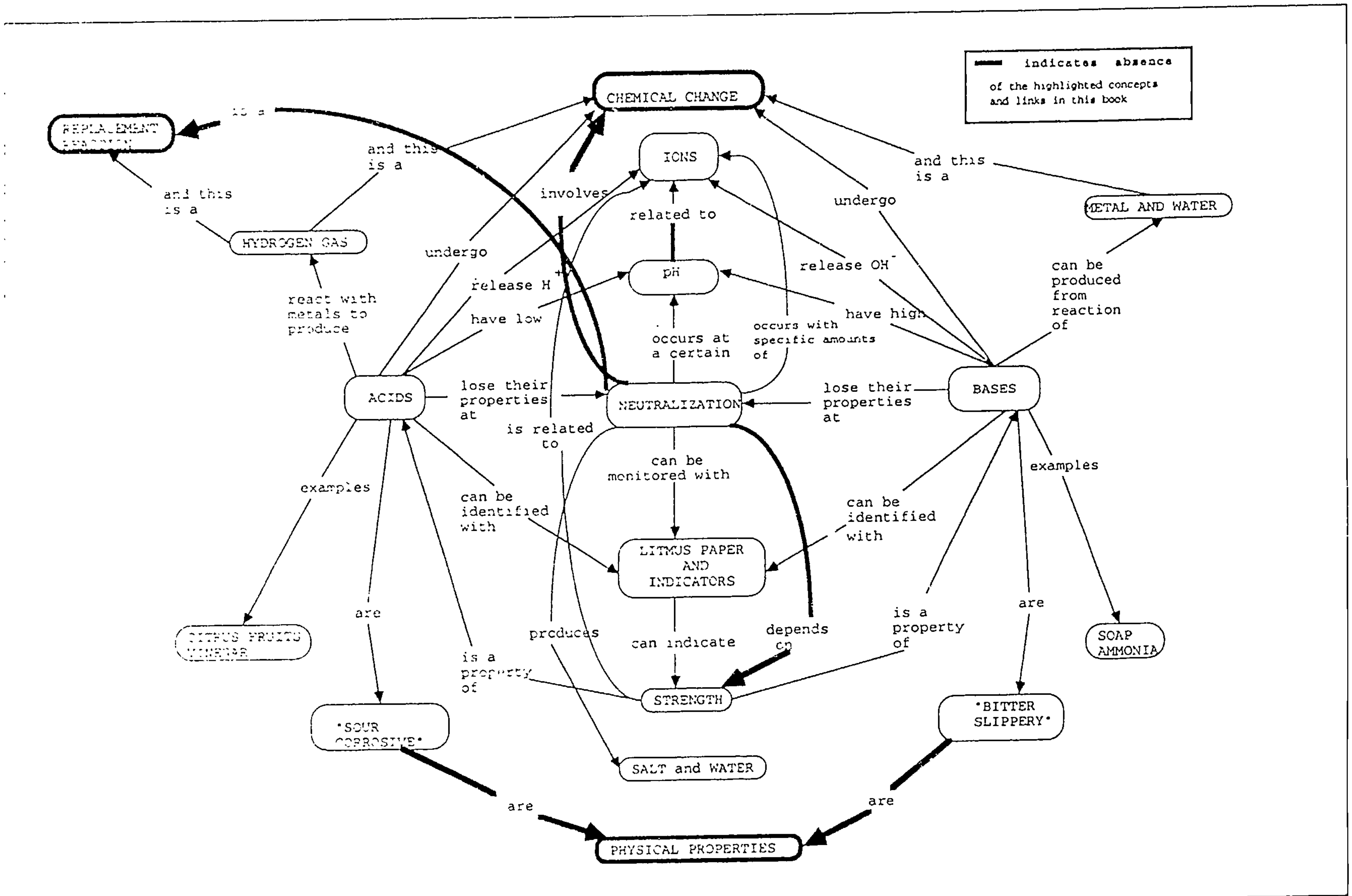

Figure 6 Conceptual framework of Textbook No 5

45

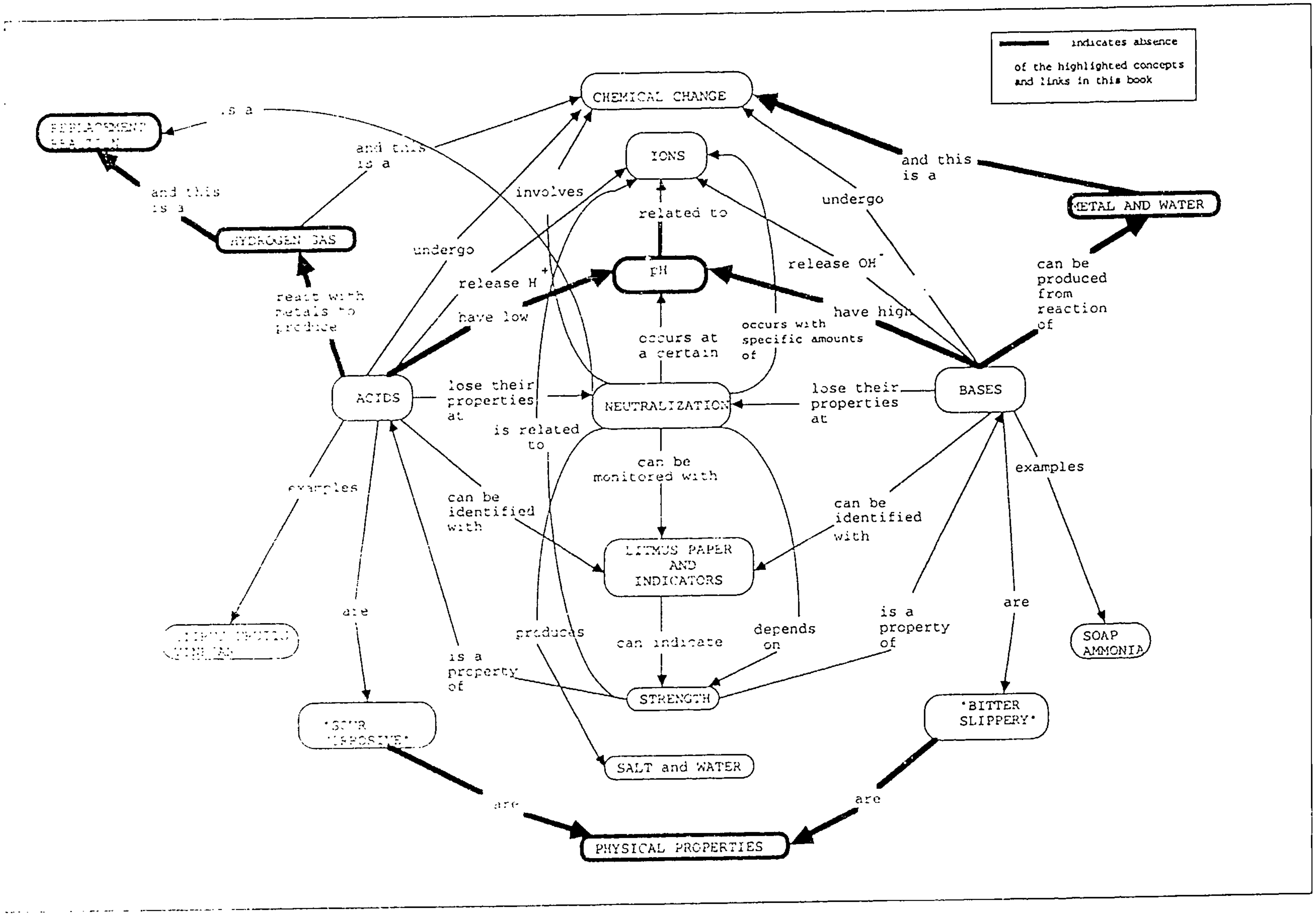

Figure 8. Conceptual framework of Textbook No. 7

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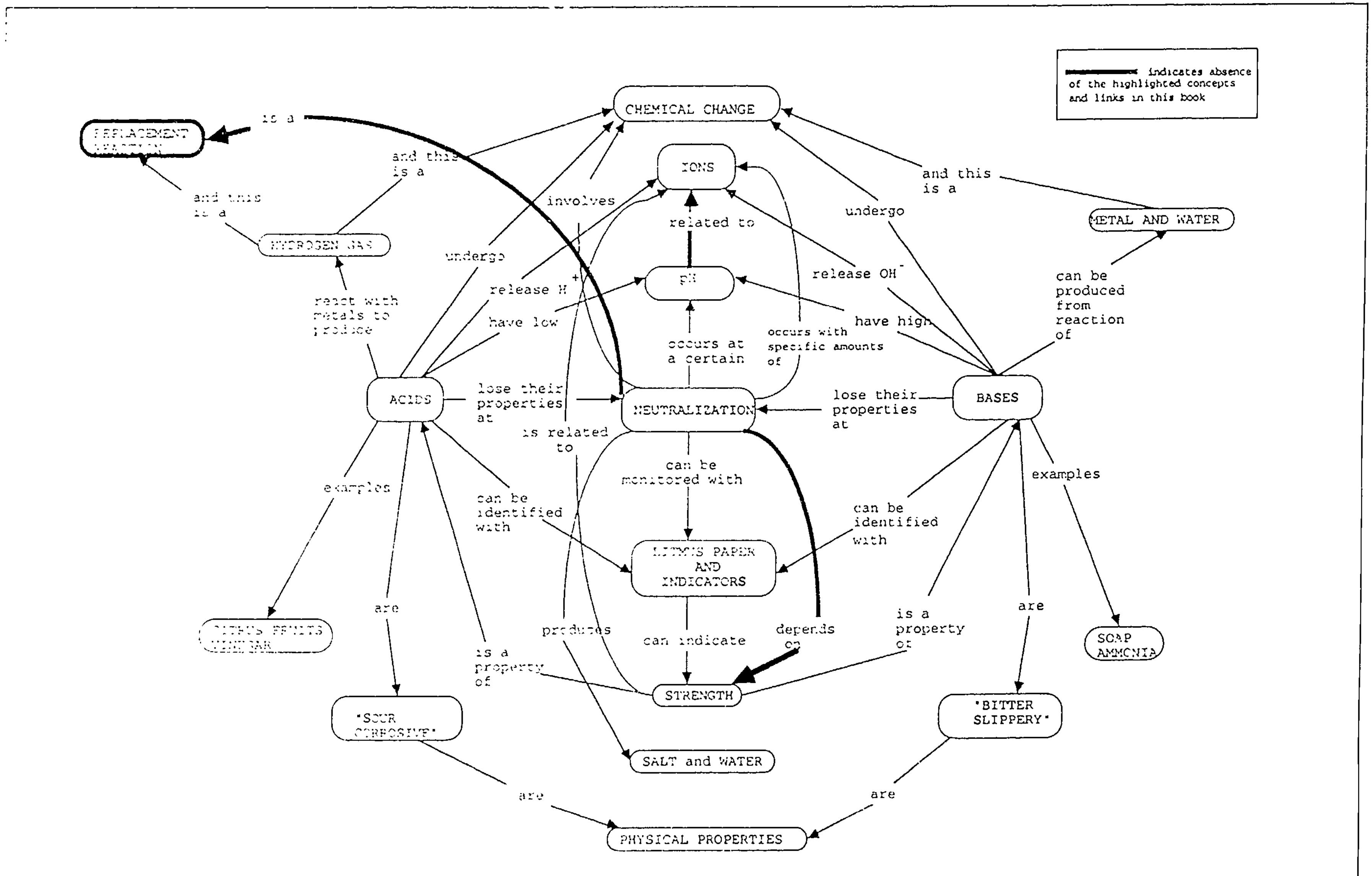

Figure 9. Conceptual framework of Textbook No. 8

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COMPARISON OF CONCEPTUAL FRAMEWORKS OF TEXTBOOKS

The distributions of concepts and links mentioned in textbooks are illustrated in **Figure 10** and **Figure 11** respectively. Overall, all textbooks made reference to most of the concepts conventionally associated with acids, bases and neutralization. However, fewer textbooks identified neutralization as a replacement reaction; synthesis of bases from water and metal; the concept of chemical change; and reference to "physical properties" (using these terms) of acids and bases. Furthermore, fewer textbooks made explicit links between mentioned properties of acids and bases and their being physical properties; pH and ions; neutralization and chemical change.

Overall, identification of neutralization as involving a chemical change as well as the relationship between neutralization and acid or base strength are missing in all textbooks. Except for Textbook No. 4, the textbooks do not characterize neutralization as a type of chemical reaction, namely a double replacement reaction. Textbook No. 5 refers to chemical equations in the discussion of neutralization but it does not characterize neutralization as involving chemical change. Except for in Textbook No. 8, chemical synthesis of acids and bases is not discussed.

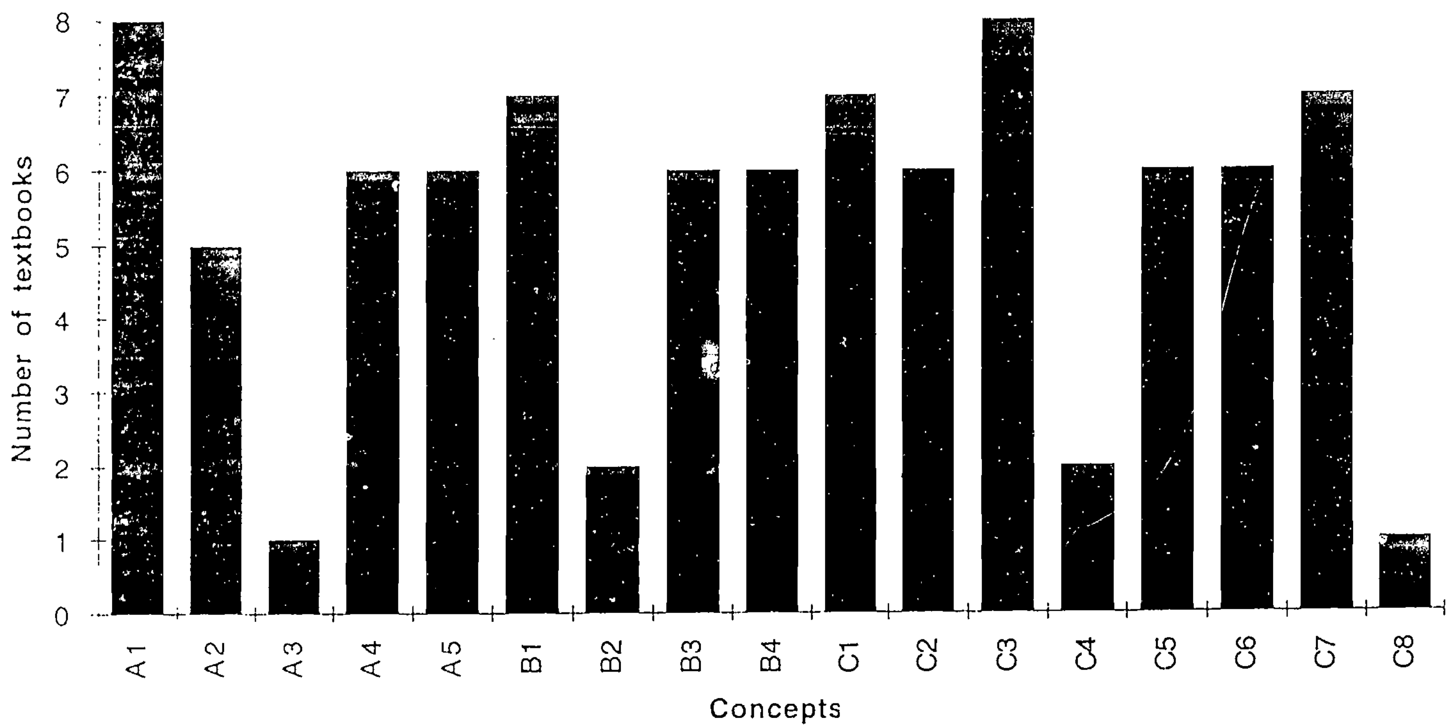

Figure 10. Distribution of concepts in textbooks

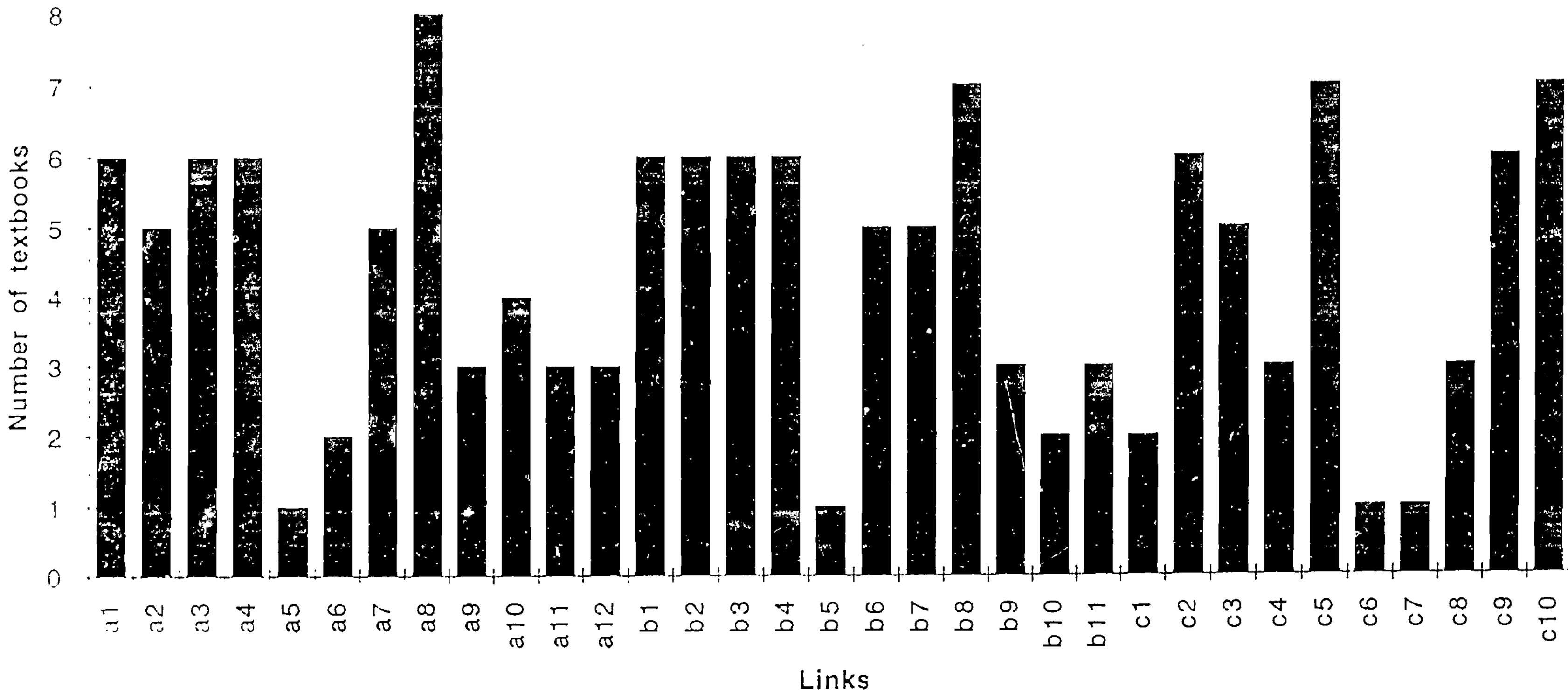

Figure 11. Distribution of links in textbooks

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COGNITIVE DEMANDS ON THE READER

Cognitive demands on the reader refer to the sorts of expectations that the text places on the reader. The reader needs to be facilitated with respect to these demands if he or she is to have a good comprehension of the text. Within the context of acids, bases and neutralization there are several kinds of such cognitive demands which are not exclusive of each other and sometimes proceed simultaneously. Here, I will identify the role of proportional reasoning, spatial configurations (as implied by text) and vocabulary with respect to text comprehension. This list is not exhaustive but it provides an orientation for what critical cognitive elements are at work as the reader proceeds through the text.

Proportional reasoning

In the discussion of acids, bases and neutralization mathematical reasoning plays an important role. For instance students are expected to reason with proportions. In order to understand the concept of strength the student needs to be able to articulate reaction of acids and bases with water to form hydronium and hydroxyl ions respectively. Weak acids and bases react less completely with water when dissolved in water. However, it is important to understand that the strength of an acid or a base is not related to its concentration (number of ions per unit volume) generated from them. What makes differential strength across acids and bases possible is not a matter of concentration but that of equilibrium, which is a concept introduced at more advanced levels and which concerns proportions by definition. None of the authors made any statements about this important distinction between concentration and equilibrium within the context of strength.

Spatial configurations

An understanding of dissolution of acids and bases requires that the students can think about ions in space-time. This means that the students need to differentiate the state of the ion in relation to the rest of the ions at a particular point in time, as well as how presence of ions of like or opposite charges affect this state. Consider the following example:

> "A strong acid or base breaks completely into ions when added to water" (Textbook No. 3, p.309).

This description which implicitly integrates the notion of strength with proportional reasoning (as discussed above), requires that the student thinks about phases of ionization and how it comes to be "complete." It provides a model for the process of ionization and is a precursor to the construction of a model for neutralization.

Vocabulary

Discussion of acids and bases involves vocabulary some of which is completely unfamiliar to students and some familiar but used in a different sense than students are used to. For example, names of chemicals (such as phosphoric acid) as well as some phenonena (such as neutralization itself) would be new to many students. On the other hand, terms such as "strong" and "weak" are accessible from everyday knowledge. However, they are used in a completely a different sense than everyday meanings associated with them. Hence, definitions might be quite problematic for students if such distinctions are not made clear and explicit. None of the textbooks studied made an effort to make such an explicit specificity in meanings of these terms.

Readers of the studied textbooks are often expected to sort ambiguous statements and the cognitive engagement in so doing can be rather challenging. Consider the following example which is the first sentence of the section on acids and bases:

> "Acids and bases are usually mentioned and studied together because they are similar in some ways and opposite in other ways. In fact, acids and bases can cancel each other out" (Textbook No. 1, p.155)

Indeed the"opposite" nature of acids and bases and how they "cancel each other out" at neutralization receive great emphasis in all textbooks:

> "In many ways, acids and bases are opposites. Acids in water release hydrogen ions and non-metallic ions. Bases form metallic ions (except for NH_4^+) and hydroxide ions. The more acidic a material is, the less basic it is." (Textbook No. 5, p.381)

I argue that the first sentences of the excerpts above would not be meaningful for most students. However, there is an important underlying message here, which a fortunate student will catch and that is the possibility of categorizing substances according to their physical and chemical properties. The opportunity to pursue this important notion of categorization and what it enables chemists to do is missed in all textbooks. The discussion simply does not go beyond what is stated as facts on acids and bases. Acids and bases "cancelling each other out" is hardly unpacked and students are expected to make inferences about its meaning: when acids and bases react with each other, there is a reduction or loss of charge in the overall solution.

CONCLUSIONS AND IMPLICATIONS

Overall the textbooks in this study are readable and contain short, straightforward sentences which are descriptive and factual. They present plenty of examples from everyday life which are often interesting. However, the textbooks fail in making explicit connections to important, underlying themes such as chemical change and physical properties. The crucial issue of how these themes interrelate therefore is not present. Furthermore, some concepts are missing or when present, are not connected into a broader conceptual framework emphasizing major concerns in chemistry.

The cognitive demands on the reader of these textbooks are quite extensive and complex. Not only does the reader need to sort out often ambiguous statements and infer meaning differences of familiar words, but also employ spatial as well as proportional reasoning simultaneously.

The results suggest that the conceptual frameworks which the students are exposed to in textbooks might be deficient not only in terms of content but also in terms of how content is presented. I argue that, (1) this analysis provides a foundation for effective text revision whereby missed opportunities for facilitating students' conceptual understanding can now be pursued; (2) taking into consideration, students' information processing based on text reading should be a component of textbook writing and revision. In future studies, comparison of conceptual frameworks across textbooks and students' understandings based on reading of these textbooks might reveal information about what sort of conceptual frameworks (inclusion/exlusion of particular concepts and links) are more appropriate for effective learning.

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Appendix 1

Textbook content

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 1

Keifer, D. R. (1991). Exploring Matter and Energy: Physical Science. Englewood Cliffs: Globe Book Company

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 2

Lamb, W. G., Cuevas, M. M., & Lehrman, R. L. (1989).
Physical Science, Harcourt Brace Jovanovich, Inc.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

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Textbook No. 3

Heimler, C. H. & Price, J. (1987). Focus on Physical Science.
Teacher Annotated Edition.
Columbus: Merrill Publishing Company

Table of Contents-Teacher's edition (1)
Using Focus on Physical Science (5)
Planning the Course (3)
Teaching Special Students (1)
Reading Science (1)
Evaluating Supplementary Materials (7)
Materials (7)
About Activities (5)
Safety in the Science Classroom (1)
Equipment and Supplies (8)
Performance Objectives (?)

Unit 1: Measurement, Force and Motion (95)
- The Nature of Science
- Force and Motion
- Laws of Motion
- Work and Simple Machines

Unit 2: Classification of Matter (75)
- Properties of Matter
- Elements and The Periodic Table
- Compounds and Bonding

Unit 3: Patterns in Matter (87)
- Metal Families
- Nonmetal Families
- Carbon Family
- Organic Chemistry

Unit 4: Changes in Matter (71)
- Solutions
- Chemical Reactions
- Acids, Bases and Salts

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 4

Boeschen, J.A., Gerard, J. A., & Storin, D. A. (1983).
Foundations: Physical Science. Teacher's Annotated Edition.
Coronado Publishers.

Table of Contents-Teacher's edition (1)
Foundations: A Science Program (4)
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Textbook No. 5

Hill, F.F. & Barcaski, P.B. (1974). Spaceship Earth, Physical Science. Teacher's Edition. Boston: Houghton Mifflin Company.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 6

Bickel, C.L., Eigenfeld, N. D. & Hogg, J. C. (1973). Physical Science Investigations. Boston: Houghton Mifflin Company.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 7

Abraham, N., Balch, P., Chaney, D. & Rohrbaugh, L.M. (1973). Interaction of Matter and Energy: Inquiry in Physical Science. Chicago: Rand McNally and Company.

*The numbers in parentheses correspond to the number of pages covering the topic indicated.

Textbook No. 8

Carter, J. L., Bajema, P. M., Heck, R. W., & Lucero, P. L. (1971). Physical Science: A problem Solving Approach. Teachers' Edition with Annotations. Boston: Ginn and Company.

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Appendix 2

Textbook content on acids, bases and neutralization

Textbook No. 1

Keifer, D. R. (1991). Exploring Matter and Energy: Physical Science. Englewood Cliffs: Globe Book Company

Title of chapter: Common Chemicals

Sub-section: Acids and Bases

- Characteristics of Acids
- Caution
- Acid Strength
- Characteristics of Bases
- Caution
- Base Strength
- Indicators
- The pH Scale
- Neutralization

Textbook No. 2

Lamb, W. G., Cuevas, M. M., & Lehrman, R. L. (1989).
Physical Science, Harcourt Brace Jovanovich, Inc.

Title of chapter: Acids, Bases and Salts

Sub-sections:

Acids
- Characteristics of Acids
- Uses of Acids
- Section Review
- Activity

Bases
- Characteristics of Bases
- Uses of Bases
- Section Review
- Careers

pH
- pH Scale
- Indicators
- Section Review

Salts
- Characteristics of Salts
- Activity
- Uses of Salts
- Section Review
- Investigation: Making Indicators

Review

Textbook No. 3

Heimler, C. H. & Price, J. (1987). Focus on Physical Science.
Teacher Annotated Edition.
Columbus: Merrill Publishing Company

Title of chapter: Acids, Bases and Salts

Sub-sections:
- Common Acids
- Common Bases
- Ions in Acids and Bases
- pH of a solution
- Determining pH
- Salts
- Esters
- Soaps and Detergents
- Anhydrides
- Technology: Acid Rain
- Frontiers: Solar Salts
- Focus on Computers: Solutes and Solvents

Textbook No.4

Boeschen, J.A., Gerard, J. A., & Storin, D. A. (1983).
Foundations: Physical Science. Teacher's Annotated Edition.
Coronado Publishers.

Title of chapter: A New View of Matter

Sub-sections:

Ionic Compounds
- Salts, Acids and Bases

Replacement: New Partnerships
- An Investigation of the Reaction of Zinc with Acid

Double Replacement & Neutralization
- Acids and Bases-Neutralization

Textbook No. 5

Hill, F.F. & Barcaski, P.B. (1974). Spaceship Earth, Physical Science. Teacher's Edition. Boston: Houghton Mifflin Company.

Title of chapter: Acids, Bases and Salts

Sub-sections:

Some properties of acids and bases
- Liquids conduct electricity
- Acids have special properties
- Bases have special properties

Testing for acids and bases
- Indicators
- How acidic or basic is it?

Neutralization
- What happens when you mix an acid and a base?
- Many common materials contain salts

Textbook No. 6

Bickel, C.L., Eigenfeld, N. D. & Hogg, J. C. (1973). Physical Science Investigations. Boston: Houghton Mifflin Company.

Title of chapter: Chemical Reactions

Sub-sections: What is a chemical reaction?

Reactions with air

Two opposite kinds of chemical reactions

Chemical Activity

Chemical activities of metals

[discussion on acids]

Textbook No. 7

Abraham, N., Balch, P., Chaney, D. & Rohrbaugh, L.M. (1973). Interaction of Matter and Energy: Inquiry in Physical Science. Chicago: Rand McNally and Company.

Title of chapter: Investigating Properties of Chemical Families

Sub-sections: Acids and Bases

Testing for Acids and Bases

Acid or Base?

Mixing an Acid and a Base

The Formation of Salt: Neutralization

Textbook No. 8

Carter, J. L., Bajema, P. M., Heck, R. W., & Lucero, P. L. (1971). Physical Science: A problem Solving Approach. Teachers' Edition with Annotations. Boston: Ginn and Company.

Title of chapter: Acids and Bases

Sub-sections: Properties of acids and bases

Acid-Base indicators

How many indicators can be used to identify acids and bases?

What are some reactions common to acid solutions?

Preparing acids and bases

How can you prepare and acid and a base?

Neutralization reactions

What are the products of a neutralization reaction?