Third Misconceptions Seminar Proceedings (1993)

Paper Title: Empowering the Learning of Chemistry Through Curriculum Development: Implications of Misconceptions Research for NSTA's Project on Scope, Sequence & Coordination of Secondary School Science Grades 6-12
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Abstract: The project on **Scope, Sequence, and Coordination of Secondary School Science (SS&C)**, initiated by the National Science Teachers Association (NSTA) in the fall of 1991 is described as a "...major effort to restructure science teaching at the secondary level." SS&C calls for "...the elimination of the tracking of students, recommends that all students study science every year for six years, and advocates the study of science as carefully sequenced, well-coordinated instruction in physics, chemistry, biology, and earth/space science" (NSTA, 1992). A prime concern of science educators in general, and chemical educators in particular, is whether there is a sound research base for this large scale reform effort. The question being examined in this paper is: Are the initiatives that the SS&C project calls for consistent with the reported findings of how students learn chemistry?

Keywords: educational methods,concept formation,theories,misconceptions,curriculum design,cognitive processes,empowering students,teaching for conceptual change,atomic theory/ kinetic molecular theory
General School Subject: chemistry
Specific School Subject: inorganic chemistry
Students: high school/ junior high

Macintosh File Name: Singh - Chemistry
Release Date: 12-16-1993 C, 11-6-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

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Empowering the Learning of Chemistry Through Curriculum Development: Implications of Misconceptions Research for NSTA's Project on Scope, Sequence & Coordination of Secondary School Science Grades 6-12.

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INTRODUCTION

The project on **Scope, Sequence, and Coordination of Secondary School Science (SS&C)**, initiated by the National Science Teachers Association (NSTA) in the fall of 1991 is described as a "...major effort to restructure science teaching at the secondary level." SS&C calls for "...the elimination of the tracking of students, recommends that all students study science every year for six years, and advocates the study of science as carefully sequenced, well-coordinated instruction in physics, chemistry, biology, and earth/space science" (NSTA, 1992). A prime concern of science educators in general, and chemical educators in particular, is whether there is a sound research base for this large scale reform effort. The question being examined in this paper is: Are the initiatives that the SS&C project calls for consistent with the reported findings of how students learn chemistry?

To answer the above question, consideration must be given to the following: (1) the rationale, philosophy, and origins of the SS&C project; (2) the chemistry sequence grades 6-12 and its proposed integration with the other science disciplines; (3) the stated research base of the SS&C project; and (4) the match between the research base of the SS&C project and the conceptual change or the more narrow "misconceptions" research within chemical education. To the degree that other reforms within the SS&C project impact chemistry, they will be examined in this paper, as well.

Over the past 15 years, there has been a strong international interest in students' conceptions concerning science phenomena. Today, major research in the area of students' conceptions is conducted at leading research centers in the U.K., Canada, and the U.S. (Driver, Guesne, & Tiberghien, 1985; Fetherstonhaugh & Treagust, 1992; Griffiths & Preston, 1989; Abraham, Grzybowski, Renner, & Marek, 1992; Nakleh, 1992). Students' conceptions which differ from scientifically acceptable ideas (hence the term "misconceptions") are significant to the SS&C reform effort because of evidence that students may undergo instruction in an area of science, perform well on tests of that subjects, yet still retain inaccurate and/or superficial conceptions of scientific phenomena. The outcome is that students undergo little meaningful conceptual change as a result of instruction. Therefore, a necessary prerequisite for the design of effective science curricula is to determine students' existing misconceptions and provide a framework within curricula addressing them. Because much of the research on misconceptions has been done outside the USA, many educators are unfamiliar with current findings on the misconceptions in chemical education. This paper examines the important chemistry topics of atoms and the particulate nature of matter, properties of matter, density, equilibria, conservation of mass, and a closely related issue of adequacy of student explanations in chemistry for students' misconceptions. General recommendations for present science reform efforts- particularly, that of the SS&C project are offered.

THE ORIGINS AND RATIONALE OF THE SCOPE, SEQUENCE, AND COORDINATION (SS&C) PROJECT

For many years the need for educational reform in the teaching of the sciences, has generally met with agreement. Presently, most science programs in the U.S. secondary schools are organized in what is commonly called a "layer cake." Students study biology in the ninth or tenth grade, then chemistry the following year, and finish with physics in the twelfth grade. Critics of the "layer cake" approach to science education charge that "...in a single year, students pursue one discipline from the descriptive to the theoretical, with little reference to prior science experiences- either in that course or other science courses- and even less reference to upcoming science experiences." (NSTA, 1992). Failure to integrate experiences and knowledge from one science class to another is blamed for the high attrition rate of students in science classes. "The emphasis on facts and rote learning and the difficulties students encounter in grasping theoretical considerations without a grounding in experience deters many from continuing in science." (NSTA, 1992).

Initiated by NSTA, the **Scope, Sequence, and Coordination of Secondary School Science (SS&C)** project targets middle and secondary school students during their formative years encouraging them to continue studying science. As such, SS&C presents itself as a self-described "...means to achieve comprehensive educational ends, presenting key science concepts, appropriately sequenced, manageable in their scope and coordinated within and between the science disciplines." (NSTA, 1992). Bill Aldridge, the project developer, urged educators to concentrate on science education for the majority of students, not just a select few, and attributed the major cause of students' disinterest and failure in science to the way science courses are structured, sequenced, and taught. He then proposed a revised U.S. middle and secondary school curriculum requiring ongoing courses in biology, chemistry, physics, and earth/space science for all students (Aldridge, 1989).

NSTA'S OFFICIAL GOALS STATEMENT

Goals

At present time the seven national SS&C project centers, (NSTA in Washington, D.C., the California Department of Education, Baylor College of Medicine and the Houston Independent School District, the University of North Carolina, East Carolina University, the University of Iowa, and Anchorage Public Schools) work toward the ultimate goal of "...science learning for all students that is interesting, relevant, challenging, and personally rewarding." (NSTA, 1992). To achieve this goal, students will learn to ask such fundamental questions as: "How do we know? Why do we believe? What does it mean? The "anticipated outcomes" of the project are as follows: " 1) a far more scientifically literate citizenry, 2) increased numbers of students, especially females and minorities, studying science at advanced levels, 3) greater understanding of scientific content, 4) new approaches to textbooks and instructional materials, and 5) improved assessment of student learning." (NSTA, 1992).

Indeed, the SS&C project goal, that of making science understandable and enjoyable for all students, is one that most science educators would deem admirable and intutively agreeable. However, the value of educational research is to qualitatively and/or quantitatively identify those practices that are effective in classrooms. It is not merely enough to identify what should happen, it is also necessary to identify how and why things happen. As the goals and outcomes are presently stated, the strengths, weaknesses, and failures of the SS&C project can only be measured over a long period of time. While there is nothing inherently wrong with the goals or outcomes of this project, a more specific set of measurable outcomes should be formulated for immediate assessment of the program. One means of providing measurable outcomes of the success of the SS&C **Content Core** is for the curriculum designers to measure the impact of the **Content Core** on students' conceptual change patterns in science. A way to do this involves ascertaining the following: (a) what conceptual knowledge do science students hold in common, (b) what are the variations in students' knowledge, (c) what are the variations in the ways students apply their knowledge to solve unfamiliar problems, (d) do the SS&C chemistry activities account for the correct and incorrect conceptions that students develop and bring to the chemistry classroom and (e) what impact (if any) does the SS&C chemistry content have upon remediating students' incorrect conceptions within that particular science discipline? Once these specific outcomes are identified and measured, only then will curriculum designers be able to assess SS&C's long term goal of improving science learning.

THE SCOPE, SEQUENCE, AND COORDINATION OF THE CHEMISTRY CONTENT CORE GRADES 6-12 AS DEFINED BY NSTA

The SS&C project developers have defined its three major components using the terms "scope," "sequence," and "coordination." The first component is termed "scope." The originators of the SS&C project envision a "coherent science curriculum spanning all six or seven secondary school years and involving all students, at all academic levels." Curriculum designers should be guided by the "less is more" principle (NSTA, 1992). The second component of the SS&C project involves sequencing of instruction, such that teachers cover science concepts over years engaging students repeatedly in different contexts to build their knowledge of the concepts and practical applications. The "coordination" of the various sciences in the SS&C project stresses examining the shared topics and processes common to biology, chemistry, physics, and the earth/space sciences for students to become aware of the interdependence of the sciences. To further assist in the coordination component of SS&C, an integrated **Content Core** has been formulated identifying the topics and subtopics deemed important by educators in science. This **Content Core** represents a core of scientific knowledge that every educated person should have at the end of his/her secondary education. The **Content Core** (devised for each of the science disciplines) serves as a guide for the design and construction of science curriculum. The **Content Core** is not itself a curriculum, but an "organizer" of the subject matter according to the tenets of the SS&C project. Educators and teachers are expected to use the document as a template for designing courses, selecting instructional materials, and conducting assessment instruments (NSTA, 1992). **Table 1** illustrates the chemistry sequence of the **Content Core** organized into three grade level groups: 6-8, 9-10, and 11-12. There is also a narrative (not represented below) describing important topics, teaching approaches, and activity ideas for the teacher.

CHEMISTRY SEQUENCE GRADES 6-12

SUB TOPICS	GRADES 6-8	GRADES 9-10	GRADES 11-12
		PROPERTIES OF MATTER	
PHYSICAL	observation of physical properties, intensive properties, extensive properties	measurement of properties: density	
CHEMICAL	color change, temperature change, production of gas or precipitate	chemical composition by mass	
SOLUTIONS	conductivity, acid/base	solubility, precipitation	solubility
		NATURE OF CHEMICAL CHANGE	
INORGANIC, ORGANIC, BIO-CHEMICAL EQUATIONS	word equations	balancing equations, simple stoichiometry	complete mole concept, complete stoichiometry, chemical reactions
ACID-BASE REACTIONS	nature of acid and base solutions ;	reacting acid and base solutions	Bronsted acids and bases,
REDOX REACTIONS	combustion	redox defined, oxidation of metals, reactivity of metals	electron transfer and reduction potentials
RATES OF CHEMICAL CHANGE	rate observed	factors affecting rate, equilbrium	derivation of gas laws
		STRUCTURE OF MATTER	
ATOMS	rationale for particulate model	structure, Periodic table	quantum model
BONDING & GEOMETRY	molecules, intermolecular bonds, phase change	valence shell model, ionic bonding simple covalent bonds	metallic bond covalent and coordinate bonds; isomers and allotropes
		ENERGY AND CHANGE	
FORMS	kinetic, potential, thermal	light and flame tests	electromagnetic spectrum
CONSER-VATION OF ENERGY/ PHASE CHANGE	conservation of energy phase change	heat/temperature during phase change	
CHANGES W/CHEMICAL REACTIONS	observation of exothermic & endothermic reactions	heats of reaction	conservation of energy, Hess's Law, heat of reaction, enthalpy diagrams
ALTERNATIVES	solar, wind, biomass	fission	fusion
		MODELS FOR CHANGE	
PARTICULATE NATURE OF MATTER	kinetic model applied to observable properties, matter in terms of kinetic model	kinetic model and gas behavior, collision theory	mathematical models and the kinetic model

Table 1. Topical table of the Chemistry Sequence Grades 6-12 as described by **SS&C** in **Volume 1- The Content Core:** A **Guide For Curriculum Designers** (NSTA, 1992) .

According to California's Dr. Michael Brugh, coordination among and between the four science disciplines is vital when utilizing the **Content Core** as a template. Two models for coordination are suggested. One model suggests that the four separate courses- biology, chemistry, physics, and earth/space science be taught simultaneously by qualified teachers in each discipline with students attending one or two periods of each science class per week. Here, coordination results from frequent conferences between the teachers seeking to coordinate topics and processes among the disciplines. According to Aldridge, the design for spacing the topics comes from Dempsters' view that science should be taught for a few hours per week over several years instead of concentrated into one year (Dempster, 1988). The second model suggests that coordination be achieved by offering each discipline in 1/4-year segments so that students learn the same level of science material each year. This model places more emphasis on the level of difficulty of the learning task. Using either model, the SS&C project designers maintain that effects of the "layer cake" approach are reduced and students are more readily able to draw connections between disciplines (NSTA, 1992).

SOME GENERAL PROBLEMS WITH SS&C CONCERNING SCOPE, SEQUENCE, AND COORDINATION

Teachers expecting to use the document in **Table 1** as a template for instruction must carefully examine the sequencing of topics in the **Content Core** for chemistry, however. The developers suggest that its design allows maximum flexibility. For example, the authors suggest: 1) that topics in each tables' first column can be distributed over three years in grades 6-8 and 2) that the content within a column can be arranged to achieve coordination among disciplines. The discipline teams have also "...deliberately sequenced the science content so that descriptive and phenomenological approaches begin the study of science in the middle level grades" (NSTA, 1992). Moving content from one grade level to another is strongly discouraged. Yet, the specific reasoning behind the sequencing of topics in chemistry at each grade level is never clearly stated and little difference appears to exist between SS&C's organization of chemistry topics and the traditional chemistry curriculum used by schools in terms of the sequencing. The same topics concerning physical and chemical properties and the atomic model are presented at the beginning of a chemistry course. However, traditionally, students experience difficulty in accurately conceptualizing these same topics (Ben-Zvi, Eylon & Silverstein, 1982, 1986; Stavy, 1988; Yarroch, 1985). Bruner long ago indicated that the sequence in which a learner encounters materials within a knowledge domain affects his or her level of mastery" but that there seemed to be no unique sequence for all learners, and that the optimum sequence in any particular case depended on a variety of factors, including past learning, stages of development, nature of the material and individual differences (Bruner, 1966). Consequently, it seems that there are many factors to consider in sequencing the content of the chemistry curriculum. Levels of intellectual activity, attitudes, development of the childrens' thinking processes and development of instruction are all important and generally considered when sequencing content within any curriculum. Inquiry into the match between the cognitive levels of students and the cognitive demands of the topics presented in science has indicated that the main difficulty in sequencing the instruction for high school science program lies in the disparity in intellectual capabilities among high school students (Shayer & Adey, 1981). Furthermore, the research activities in the cognitive field of science education have moved from that of a more generalized to a more specialized concern with categorizing students' misconceptions of scientific phenomena and/or concepts within each discipline, developing diagnostic tools for identifying students' ideas of science, and utilizing sequenced approaches in instruction to identify and track conceptual change among students. Findings from this more specific research must be incorporated into science curricula because it has important implications for the sequencing of instruction. Yet, despite these advances in research, the curriculum in chemistry has traditionally remained heavily content laden with learning objectives sequenced in order of complexity according to Bloom's (1956) taxonomy. Only exceptional students and teachers investigate the skills, content, and processes of science beyond the comprehension or application level of Bloom's taxonomy. Furthermore, content from year to year or from science discipline to discipline is not effectively or systematically reintroduced as should be the case with any science program based on a true spiral approach. Given these disparities between the documented problems of learning and teaching science and the ways in which science curriculum has been designed, it is questionable as to whether the **Content Core** and its chemistry sequence grades 6-12 represents much of a significant change in its sequencing of topics from that of earlier curricula in chemistry. Heavily content-laden topics are presented in similar order to that of other chemistry curricula and each topic builds from a basic understanding of such concepts as the knowledge of atoms and molecules. Inadequate understanding of one concept no doubt affects students' mastery of other topics and teachers may find themselves remediating students before they can teach those topics recommended at a particular grade level. Additionally, the initiatives of the SS&C project require teachers to effectively and accurately sequence, integrate, and coordinate their teaching of the chemistry content with the other science disciplines.

A SUMMARY OF RESEARCH IN CHEMICAL EDUCATION

A search of the ERIC Educational Database from 1982-1992 reveals generalized trends of research at the secondary level within the science disciplines. Most of the secondary science education research of the past decade concentrates on the disciplines of biology and physics while research concerning chemical education ranks third. Teaching methods and curriculum dominate all areas of research in science education with over 50% of the articles. Research into misconceptions comprises less than 4% of the total research in biology and secondary education, 8% of the total research in physics education at the secondary level, and 5% of the total research within chemical education. Other major areas of research in chemical education include student characteristics, testing and evaluation, and technology and microcomputers.

What is not easily revealed by such a generalized search of the ERIC database is how the studies of students' cognitive processes and conceptual development has evolved (including the important studies of misconceptions) over the past decade. While research into teaching methods and curriculum has continued to dominate chemical education, increased attention has been paid to cognitive studies which now make up 12% of the total research reports in chemical education. This trend of greater numbers and varieties of research in the cognitive field is revealed in literature reports of 1984, 1988, 1989, 1990 as shown in **Tables 2** and **3** on the next pages.

Table 2 compares the percentages and breakdowns of the categories of research in each of the three science disciplines. Research into student misconceptions predominates only in the discipline of physics where it comprises 20% of the cited research concerning physics and secondary education in 1984, the last year when research reports were categorized and separated by topic into specific content areas and educational levels.

MAJOR CATEGORIES AND PERCENTAGES OF TOTAL RESEARCH FOR SECONDARY CHEMISTRY, BIOLOGY, AND PHYSICS FOR 1984

% of total research			
Chemistry	Biology	Physics	Category
29	23	50	teaching methods
18	18	10	curriculum
18	-	10	testing
12	8	-	student characteristics
6	8	20	student misconceptions
-	13	-	AP courses
12	-	-	problem- solving
-	21	-	textbooks
6	8	-	technology/microcomputers
-	5	10	student attitudes

Table 2: A categorized comparison of percentages of research reports dealing with the three major scientific disciplines taught at the secondary level.

Table 3 reveals a summary of the research topics in science education for 1988, 1989, and 1990. Between 1988 and 1990, there is little change in the categories of research, but there is a shift of interest towards studies of conceptual development (including reports on students' and teachers alternate conceptions and conceptual change). In 1990, the single largest category of research is conceptual change and achievement (accounting for more than 14% of the total 281 research articles cited for that year). The papers that make up this category were divided into five relatively distinct categories. The studies dealt with questions about students' prior knowledge, understanding how conceptual change occurs, teaching categories, concept mapping, and factors influencing students' conceptions or achievement. Other current research interests include curriculum and instructional intervention studies, teaching characteristics, equity issues in science education, student attitudes/preferences, and teacher preparation.

MAJOR CATEGORIES OF RESEARCH IN SCIENCE EDUCATION FOR 1988, 1989 AND 1990
(as reported in **Science Education**)

% of total research in literature	category	compilers/editor (year)
15%	conceptual developmen	Koballa,Crawley &Shrigley (1988)
15%	achievement	
12%	professional concerns	
12%	teacher education	
12%	problem solving	
9%	programs	
9%	curriculum	
9%	attitude	
5%	instruction	
2%	epistemology	
30%	achievement in science	Baker (1989)
23%	affect	
15%	curriculum	
15%	teachers	
10%	cognitive processes	
9%	computers	
7%	textbooks and text comprehension	
6%	tests and assessments	
6%	instruction	
5%	misconceptions	
3%	scientific literacy	
2%	women and minorities	
2%	classroom interactions	
2%	legislation and poiicy	
14%	conceptual change and achievement	Finley, Lawrenz & Heller (1990)
9%	curriculum and instructional intervention	
9%	teacher characteristics	
8%	equity issues	
7%	student attitudes and preferences	
7%	teacher preparation	
6%	assessment and research design	
6%	technology	
5%	problem solving	
5%	policy studies	
5%	international science education	
4%	informal science centers	
3%	cognitive development and logical reasoning	
3%	the nature of science	
3%	the analysis of science textbooks	
2%	science process/inquiry skills	
2%	science, technology, and society	
2%	students with special needs	

Table 3: A categorized comparison of percentages of research topics for 1988, 1989, and 1990 as reported in **Science Education** and associated editors or compilers of the articles.

As illustrated in **Tables 2** and **3**, the reviews of science education research by Koballa et. al., (1988), Baker (1989), and Finley et. al., (1990) reveal the changes in science education research. The complexity of research in science education is increasing, for many of the cited reports address multiple issues and could fit two or three categories. Secondly, researchers in science education are beginning to address this complexity of issues in science education by using a variety of research methods including: standard experimental activities, ethnographies, in-depth clinical interviews, philosophical analyses, surveys, Delphi studies, and cost effectiveness analyses. Thirdly, not only do the summaries of research in science education function as a historical record of the research reported during a single calendar year, but by examining consecutive annual summaries, one can recognize trends in the research and note priorities and cessations in the coverage of themes. Fourthly, it does appear that the greatest area of current research interest is in the category of conceptual change. Larry Yore (1990) notes that the single largest category of conceptual development studies is the descriptive studies detailing learners' prior knowledge or misconceptions.

WHAT MAKES CHEMISTRY SO HARD

Chemical education has a major problem distinguishing it from biology and physics. Chemistry is a laboratory-based science requiring students to synthesize instructions, prepare materials, and record both quantitative and qualitative data precisely. Inherent in students' analyses of the laboratory products (often directly unobservable) are fairly complex calculations requiring interpretation at several levels. Since much of chemistry is not directly observable, students are forced to progress initially from purely descriptive chemistry (characterized at the level of concrete operations) to more theoretical and less descriptive chemistry (characterized at the level of formal operations). At the concrete stage, things are accepted, or learned, for themselves. At the formal stage students are required to draw upon the relationships that are an integral part of modern chemistry. Research indicates that many students who study chemistry in high school do not progress to the level of mental maturity required for such studies. Furthermore, even mature students revert to concrete reasoning when they are confronted with new and foreign topics (Shayer & Adey, 1981). For that reason, many agree with G.M. Barrows (1991), who maintains that it is accepted that at the high school or college entry stage, chemistry does not make sense and that remedial actions are based on matters that are peripheral to what goes on in the minds of students in the classroom and teaching laboratory. The insights into the learning process that are provided by experienced teachers and by educational psychologists are generally ignored, and it is Barrow's opinion that reforms easily fall into the hands of "educational dilettantes."

Increasingly, chemical educators are beginning to examine students' understandings and misunderstandings of scientific phenomena and/or concepts. Research evidence demonstrates that students frequently bring to their classes science concepts that differ from those generally accepted by professional scientists. Indeed, it has been suggested that the most important things that students bring to their classes are their concepts. Writers from the cognitive, the developmental, the behavioral, and the constructivist perspective, all indicate that knowledge of learners' conceptions and misconceptions is of particular importance to educators (Ausubel, Novak, & Hanesian, 1978; Piaget, 1964; Shayer & Adey, 1981; Gagne, 1970; Driver & Oldham, 1986; Osborne & Wittrock, 1983).

Research in students' conceptual knowledge of chemistry is based on a model of learning in which students construct their own concepts (Wittrock, 1978; Osborne, Bell & Gilbert, 1983). According to this cognitive model of learning, learners generate their own meaning based on their background, attitudes, abilities, and experience. Research has indicated that one reason why students at all levels struggle to learn chemistry and are often unsuccessful is because students are not able to construct appropriate understandings of chemical concepts. Students construct pseudo-scientific or non-scientific notions referred to in the research literature as "alternative frameworks" or "misconceptions," "intuitive beliefs," "preconceptions," "spontaneous reasoning," "children's science," and "naive beliefs" (Driver and Easley, 1978; Fisher, 1983; McCloskey, 1983; Anderson and Smith, 1982; Viennot, 1979; Gilbert, Osborne, & Fensham, 1982; Osborne, Bell, & Gilbert, 1983; Caramazza, McCloskey, & Green, 1981). In this paper, the term "misconceptions" will be used to mean any conceptual idea whose meaning deviates from the one commonly accepted by professional scientists. Once integrated into a student's cognitive structure, these misconceptions interfere with subsequent learning. The student is then left to connect new information to a cognitive structure that already holds inappropriate knowledge. Thus, the new information cannot be connected appropriately to a cognitive structure, and weak understandings or misunderstandings of the concept occur.

A review of the research relating to students' misconceptions indicates many common findings. First of all, pupils have intuitive everyday conceptions of physical and chemical phenomena, before they receive formal instruction about them; these everyday conceptions can be categorized. Secondly, everyday conceptions within a particular field are not predictable but have to be discovered, and each field therefore has to be studied separately. Thirdly, everyday conceptions disrupt and impede the learning of other concepts contained in school courses. Fourthly, teachers are little acquainted with these everyday conceptions and their importance for learning. And finally, the effect of school instruction in improving pupils' scientific thinking is not very large (Andersson, 1982). More recently, studies indicate that students' conceptual changes are influenced by a variety of students factors including basic assumptions, interactions of declarative and other types of knowledge, "point of view" about explanations, general conceptual system, sociocultural factors, and student attitudes (Greene, 1990; Stavy, 1990; Linder, 1990; Jackman, Moellenberg, & Brabson, 1990; Okebukola & Jagede, 1990; Gooding, Swift, Schell, Swift, & McCroskery, 1990).

THE WEAK MATCH BETWEEN THE SS&C CHEMISTRY CONTENT CORE TOPICS AND THE RESEARCH IN MISCONCEPTIONS

While the range of chemistry concepts which have been investigated is not extensive, those documented chemical concepts presenting barriers to student learning must be carefully evaluated and their findings applied to SS&C. Initiatives in the chemistry sequence of the **Content Core** must allow for students to correctly restructure their knowledge to correct many of their misconceptions. To illustrate the needs, selected topics from the Chemistry Sequence Grades 6-12 and the written objectives are summarized and compared with the research literature about student misconceptions or alternative frameworks.

The **Content Core's** chemistry sequence, grades 6-12, is shown in **Table 1**. Subtopics such as physical and chemical properties, atoms, rates of chemical change, forms of energy and particulate nature of matter are grouped under five content organizers. The five content organizers selected for examination are: 1) the properties of matter, 2) the nature of chemical change, 3) the structure of matter, 4) energy and change, and 5) models for change. Furthermore, the subtopics are grouped by grade levels. Samples of selected subtopics within each content organizer (taken from **Table 1**), objective, or skills are listed along with a summary of citations of students misconceptions for each grade level in **Tables 4**, **5**, and **6**.

CHEMISTRY SEQUENCE SUBTOPICS, SPECIFIC CONCEPTS (AS REPORTED IN **VOLUME 1: THE CONTENT CORE: A GUIDE FOR CURRICULUM DESIGNERS** BY NSTA, 1992) AND CITATIONS OF RELATED STUDENTS' MISCONCEPTS FOR GRADES 6-8.

subtopics	specific concepts	literature citations of misconcepts
physical properties	observation of physical	Ben-Zvi, Eylon, & Silberstein (1982,1986)
	extensive properties	students attribute intensive properties like color and malleability to atoms
	intensive properties	
oxidation-reduction reactions	combustion	Andersson(1986);Driver(1985) students use nonscientific ideas for chemical reactions
atoms	rationale for particulate model	Stavy(1988);Yarroch(1985) Ben-Zvi, Eylon & Silberstein (1982, 1986) (Pfundt, 1981) students don't understand or apply the model.
changes with chemical reactions	observation of exothermic and endothermic reactions	
particulate nature of matter	the kinetic model applied to observable properties	Stavy(1988);Yarroch(1985) students easily apply model to gases, not solids or liquids
	matter pictured in terms of the kinetic model	

Table 4: Selected subtopics and concepts (as reported in SS&C's Chemistry Sequence of the **Content Core** for grades 6-8) and matching literature citations of students related misconceptions.

CHEMISTRY SEQUENCE SUBTOPICS, SPECIFIC CONCEPTS (AS REPORTED IN **VOLUME 1: THE CONTENT CORE: A GUIDE FOR CURRICULUM DESIGNERS** BY NSTA, 1992) AND CITATIONS OF RELATED STUDENTS' MISCONCEPTS FOR GRADES 9-10

subtopics	specific concepts	literature citations of misconcepts
chemical properties	chemical composition by mass	
iorganic,organic, biochemical equations	balancing equations simple stoichiometry	Ben-Zvi, Eylon & Silberstein (1986) Yarroch (1985) students viewed balancing equations as a mathematical exercise; little atomic explanation offered
atoms	the structure of the atom atomic structure and the periodic table	Griffiths & Preston (1989) Cros et. al. (1986) students revealed misconceptions relating to structure, shape, size,
conservation of energy and phase change	heat and temperature during phase change	Duit and Kesidou (1990) Andersson (1982); Wiser (1988, 1986) students do not differentiate heat and temperature; the temperature of a boiling liquid changes.
particulate nature of matter	the kinetic model applied to behavior of gases	Stavy (1988) Furio Mas, Perez, & Harris (1987) students apply the model inconsistently; gases viewed as weightless

Table 5: Selected subtopics and specific concepts (as reported in SS&C's Chemistry Sequence of the **Content Core** for grades 9-10) and matching literature citations of students related misconceptions.

CHEMISTRY SEQUENCE SUBTOPICS, SPECIFIC CONCEPTS (AS REPORTED IN **VOLUME 1: THE CONTENT CORE: A GUIDE FOR CURRICULUM DESIGNERS** BY NSTA, 1992) AND CITATIONS OF RELATED STUDENTS' MISCONCEPTS FOR GRADES 11-12

subtopics	specific concepts	literature citations of misconcepts
properties of	solubility and solubility equilibriums	Gussarsky & Gorodetsky (1990) students do not understand the dynamic nature of equilibrium
	LeChatelier's principle	
oxidation-reduction reactions	electron transfer and reduction potentials	Ben-Zvi, Eylon, & Silberstein (1986) students view such reactions as static
bonding and geometry	metallic bond	
	covalent and coordinate bonds	Peterson, Treagust & Garnett (1989); identified 8 misconcepts
	isomers and allotropes	
changes chemical reactions	conservation of energy & Hess's Law	Hesse & Anderson (1992) de Vos & Verdonk (1987)
	heat of reaction	Granville (1985)
	enthalpy diagrams	students have difficulty conserving mass and energy
particulate nature of matter	mathematical models and the kinetic model	Sawrey (1990) Pickering (1990) Nurrenbern & Pickering (1987) university students can solve algebra, but not explain the particulate model of gases.

Table 6: Selected subtopics and specific concepts (as reported in SS&C's Chemistry Sequence of the **Content Core** for grades 11-12) and matching literature citations of students related misconceptions.

Tables 4, **5**, and **6** list some chemistry subtopics from the SS&C chemistry content core and gives the specific concepts or skills that students are to investigate in the second column. In the third column are citations of research concerning students' misconceptions. Although, there are more studies of students' misconceptions spanning all grade levels for each of the selected subtopics in chemistry, the studies cited in **Tables 4**, **5**, and **6** deal specifically with students' misconceptions in the subtopics identified by grade level in the **SS&C** content core. The variety and number of students' misconceptions might well be expected to negatively impact the reforms.

The Atomic Model And Particulate Nature Of Matter And Students' Misconceptions Of These Topics

A closer examination of the misconceptions reveals some of the problems and raises questions concerning the adequacy of the SS&C project's research base. The SS&C guidelines suggest the following teaching points for the particulate or atomic model:

-Grades 6-8: Teachers provide activities allowing students to directly observe the electrical properties of matter. Later, the teacher guides students to the atomic model with its positive nucleus, negative electrons, etc.,

-Grades 9-10: Teachers provide "black box" activities allowing students to gain experience in constructing models; teachers should introduce the basic particle of the atom and the periodic table.

-Grades 11-12: Teachers provide students with a more complete and accurate description of the atom and its electron arrangements complete with line spectra as evidence for the discrete energy levels in the atom (the quantum model) (NSTA, 1992).

However, misconceptions research reveals that students from elementary school through the university level maintain a primitive perception of matter (solids, liquids, and gases) as a continuous medium, rather than as an aggregation of particles and that students do not internalize important aspects of the accepted particulate or atomic model of matter. Research indicates that this widespread misconception is held by over half of the students from junior high school to senior high school to the university level (Novick and Nussbaum, 1978, 1981; Nakleh, 1992; Doran, 1972). In addition, numerous other student misconceptions exist concerning the concepts of atoms and molecules. These misconceptions reveal that large numbers of students do not fully understand the basic, particulate nature of all matter. Among the specific misconceptions reported in research are the following:

-Students in grades 2-7 differentially accept the idea of the atom as the basic building block of matter (Pfundt, 1981).

-Students in grades 6-7 believe molecular diameter decreases progressively from solid to liquid to gas for a given substance (Dow, Auld, and Wilson, 1978).

-Students in grades 10-11 believe that bulk properties of a substance-such as electrical conductance, color, and malleability- are also properties of a single atom (Ben-Zvi, Eylon, & Silberstein, 1986).

-Students in grades 10-11 can't state that balanced chemical equations represent rearrangements of atoms because they hold a static, rather than kinetic, view of matter (Yarroch, 1985); (Ben-Zvi, Eylon & Silberstein,1986).

-Students in grades 11-12 believe that molecules are much larger than they probably are (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that molecules of the same substance vary in size (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that molecules of the same substance change shapes in different phases (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that molecules have different weights in different phases (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that atoms are alive (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that water molecules are composed of solid spheres (Griffiths & Preston, 1989).

-Students in grades 11-12 believe that molecules expand when heated (Griffiths & Preston, 1989), subjects' grades 11-12

-Students in grades 11-12 believe that the size of an atom depends on the number of protons it has (Griffiths & Preston, 1989).
-First year college undergraduates can name the parts of an atom or a nucleus, but can't describe the interactions of these particles (Cros et al.,1986, 1988).
-First year college undergraduates invoke a simplistic Bohr model of the atom in their explanations (Cros et al.,1986, 1988).

Chemistry is a science whose primary purpose is the description and explanation of physical and chemical changes around us. It is a discipline requiring students to jump from the phenomonological level (i.e. observed changes in substances) to the atomic molecular level, which explains observable changes in terms of the interactions between atoms and molecules. This poses problems for students, teachers, and curriculum designers because it appears that many of the misconceptions cited in **Tables 4**, **5**, and **6** reveal not only students' weak understandings of the atomic model but also of physical and chemical changes, chemical reactions, and conservation of mass and energy and equilibria. The students' misconceptions are incompatible with atomic-molecular theory, which is basic to the study of chemistry and a major topic in every chemistry class. This fundamental idea of atoms and molecules is essential to the learning of other concepts such as chemical bonding, chemical reactions, states of matter, and equilibria. Thus, it seems clear that any misconception students harbor about atoms and molecules will impede further learning.

<u>Properties Of Matter And Students' Associated Explanations of Chemical Change and Misconceptions Of Density, Equilibria, And Conservation Of Mass</u>

According to SS&C guidlines, some suggested teaching points concerning the properties of matter for each grade level are :
-Grades 6-8: Teachers are to provide activities allowing students to classify and separate materials based on direct observation of the properties of matter, to observe many different chemical and physical changes, and to observe the properties of solutions.
-Grades 9-10: Teachers are to present activities allowing students to describe more quantitatively the properties of matter (especially density) that they observed in grades 6-8. Teachers can introduce the mass of a mole of a substance and how to determine the formula of a compound. Also teachers are to introduce the concepts of solubility, precipitation, and concentration of solution.
-Grades 11-12: Teachers are to provide students with activities allowing students to apply their previous knowledge of solutions and solubility to the concept of equilibrium (NSTA, 1992).

The above teaching suggestions of SS&C assume students have a thorough understanding of the following concepts: (1) atoms and molecules, and (2) the particulate model of matter. However, research on misconceptions clearly indicates the failure of most students to understand: (1) the concepts of atoms and molecules, (2) the particulate model of matter, (3) the process of chemical changes, and (4) the physical and chemical properties of matter. Furthermore, misconceptions research indicates that students experience conceptual difficulty in applying scientific knowledge to their explanations of the properties of matter, particularly chemical change. For example, in Sweden, students (ranging in age from 12-15 years where chemistry instruction starts in grades 7 and 8) were asked to explain the appearance and disappearance of substances in a chemical change. As an example, students were asked " *Why do shiny copper water pipes turn dull and tarnished?"* or " *What happens when a nail rusts?*". At least 90% of the students had studied oxidation. The students' answers fell into the following 5 categories:

1. *It's just that way.* In this case, students are simply uninterested in the change. It's just something that they notice happens.
2. *Displacement from one physical location to another occurs.* In this category, students envision that a coating simply materializes, either from the air, as a with rust on a nail, or from the water inside the pipes.
3. *The material is modified.* In this view, students argue that what appears to be a new substance is actually the original substance-just in a modified form. An example of this would be when a student thinks that the copper pipe simply turns dark because of heat. They think that it continues to be the same substance, although it does look different.
4. *Transmutation occurs.* Students in this category would explain that steel wool gains weight as it burns because the steel wool is changed into carbon, which is heavier. In this view, atoms simply change into a new kind of atom.
5. *Chemical interaction occurs.* This is a category where acceptable answers are found. Typically the student states that oxygen in the air reacts with the copper pipe to form a copper oxide coating on the pipe. For the other question, they think that the steel wool burns because oxygen combines with the iron. At best, only 15% of the students in the study could answer the last problem correctly. These results show students' lack of understanding of the following underlying conceptions: a) that matter is composed of particles, b) that these particles are in constant motion, c) that these particles can react with each other by breaking or forming bonds (Andersson, 1986).

Andersson's results illustrate a significant problem that students encounter in their studies of chemistry. Since many concepts taught within chemistry build from students' knowledge of the atomic model, concepts associated with atoms and the actions of atoms are used in almost all explanations of chemical change, and students rarely use this knowledge in their explanations. Given the documented difficulties that students have with the most fundamental notion of the atom, it is not reasonable to expect all students to be able to comprehend and distinguish between physical and chemical properties at grades 6-8, master density and chemical composition both quantitatively and qualitatively at grades 9-10, or explore properties of solutions, and then apply this knowledge to the very advanced and important concept of chemical equilibrium, in grades 11-12, as the SS&C teaching guidelines clearly suggest students should be able to do. The research literature is replete with the difficulties that students experience concerning physical and chemical changes, density, equilibria and conservation of mass. Some of these student misconceptions include the following:

<u>Physical And Chemical Changes</u>

-Students in grades 2-12 describe the bubbles formed by boiling water as being made of air, oxygen, or hydrogen. Many also cannot explain how a saucer held over boiling water becomes wet and why it dries when removed from the steam. Students use the terms "condensation" and "evaporation" with poor understanding of the meaning (0sborne & Cosgrove, 1983).

-Twenty-five percent of the chemistry graduate students in a class state that the composition of the bubbles rising from a beaker of boiling water consist of air, oxygen, or hydrogen (Bodner, l991).

-Many students in grades 2-12 view only physical changes as reversible and chemical changes as irreversible (Stavridou & Solomonidou, 1989).

Density

-Students in grades 1-7 experience difficulty understanding density (the first intensive physical quantity encountered) because it is unobservable and must be inferred from knowledge about weight and size (Smith, 1985, 1986, 1987).

Equilibrium

-Students in grade 12 do not perceive the equilibrium mixture as an entity; rather, they manipulate each side of the chemical equation independently, as if balancing the equation (Gussarsky & Gorodetsky, 1990).

-Students in grade 12 fail to understand the dynamic nature of equilibrium assuming that reaching a balanced condition means no further reaction will occur (Gussarsky & Gorodetsky, 1990).

-Students in grade 12 confuse everyday meanings of equilibrium with chemical equilibrium (Gussarsky & Gorodetsky, 1990).

Conservation Of Mass

-Students in grades 6-7 conserve mass when a ball of clay is reshaped, but have difficulty conserving matter during a more complex physical change like dissolving (Piaget & Inhelder, 1941).

-Students in high school apply nonscientific, intutive ideas based on life experiences in their explanations of chemical changes like burning, rusting, and the combustion of elemental phosphorus i.e. "things get lighter when they are burnt." (Driver, 1985).

-Students in high school do not focus upon gaseous reactants and products in their considerations of conservation of mass and energy in a chemical system (Driver, 1985).

Students' Explanations

Students show poor understanding of what constitutes acceptable explanations in chemistry. Solomon (1983) has identified four kinds of scientific explanation given by elementary school children: (a) explanation by suggesting that that's the way things naturally are; (b) explanation by redefinition or word substitution; (c) explanation by simile, analogy, model, and metaphor; and (d) explanation based upon scientific theory. Only the third and fourth kinds of explanations are readily acceptable to the chemist. Similes, analogies, models, and metaphors can play an important role in the development of mature scientific thinking, but some analogies or models are more productive than others. Hesse and Anderson (1992) investigated students' conceptions of chemical change and their explanations in terms of the metaphors and analogies that students use. High school students were shown three oxidation-reduction reactions and asked to explain them. All of the students were asked to explain their responses, evaluate the quality of their responses and compare them to other hypothetical responses. Findings from the research indicate that:

-Students in grades 11-12 substitute everyday materials and energy for chemical substances in their explanations (Hesse & Anderson, 1992).

-Students in grades 11-12 consistently demonstrate their inability to shift their explanations to the atomic-molecular level (Hesse & Anderson, 1992).

-Students explanations' in grades 11-12 include everyday but superficial analogies (Hesse & Anderson, 1992).

-Students in grades 11-12 view analogies with everyday events as sufficient for their personal explanations, and contend that chemical explanations differ mainly in their technical vocabulary using "fancy words" or "sounding scientific." (Hesse & Anderson, 1992).

Recommendations For SS&C Curriculum Designers

Space limitations allow only for discussion of a few of the ways students incorrectly conceptualize chemistry topics, but there is no doubt that misconceptions are present in a large range of science concepts, and that they hinder students in attaining an understanding of science, or contribute to the poor performance of many students in all aspects of science. Misconceptions may develop prior to formal instruction as a result of the variety of contacts students make with the physical and social world (Strauss, 1981), or as a result of interaction with teachers (Gilbert and Zylberstajn, 1985), or from inadequate textbooks or students' inabilities to understand textbook presentations (Cho et al., 1985). The misconceptions cited in **Tables 4**, **5**, and **6** and others discussed in this paper are instructionally significant for curriculum because a) they are believed by many students regardless of academic preparation and grade level, b) they are held with a deep conviction and cannot be easily abandoned and c) they hold the promise of being changed with proper instruction.

Patterns found in the students' responses demonstrate that misconceptions should be of significant concern to the designers of SS&C's **Content Core** and its chemistry sequence 6-12. Though SS&C's chemistry sequence lays out the content of the discipline, it fails to take into consideration the overwhelming evidence that many students experience conceptual difficulty understanding and utilize the most basic concepts of chemistry. Thus, the conclusion is that the initiatives of SS&C are inconsistent with the ways in which students learn chemistry. Therefore, the following recommendations are made.

Curriculum designers must bridge the gap between research and teaching concerning the needs of students and teachers. Researchers and curriculum designers need to seek to discover the cognitive levels of students to appropriately sequence topics and concepts in grades 6-8 and 9-10 and match them to the curriculum content efforts. Curriculum developers must also ask themselves the following questions: (1) What are the conceptions of natural phenomena students can be expected to bring to and develop in the classroom? (2) During instruction, how should students' misconceptions be addressed? (3) How should presently taught topics be analyzed? and (4) What changes in students' knowledge occurs with various curriculum innovations? If the findings of researchers are not included, curriculum designers risk repeating past mistakes or changing what should be maintained. Constructivist theories of conceptual change require that students' initial conceptions be identified and, if erroneous, confronted before more adequate conceptions can be taught. As such, collaboration between curriculum developers and researchers in cognitive theory and conceptual change is necessary for effective and lasting reform in curriculum.

The educational efforts of the 1960's indicate that localized, short-term improvements are possible, but the fact that the efforts of the 1960's produced little lasting change indicates that true reform is much more difficult to achieve. Thus, long-term, comprehensive research projects must be initiated that assess both the process and product of reform. These projects should encourage the creation of research networks. Projects of this nature ensure that a sound theoretical framework underpins the systemic inquiry of science curriculum reform which will improve the quality of research and in turn, contribute to sustainable reform.

Of particular importance in the SS&C initiatives is the need to provide activities and materials that address students' misconceptions concerning the atom and the particulate model of nature at all grade levels. Similarly, the topic of chemical change deserves special attention. These topics are not as simple for students to comprehend as has been believed in the past. If students are to acquire accurate scientific conceptions, both teachers and curriculum designers need to anticipate the deeper misconceptions that affect students' thinking. Teachers must be made aware through inservicing and workshops of students' documented misconceptions in a given topic or subject and trained in methods of inducing cognitive dissonance and conceptual change in students.

Curriculum designers and teachers share in the responsibility of helping students to understand why some kinds of explanations are preferable to others. The function of analogy should be addressed directly; students should be taught that although analogy and metaphor play an important part in scientific explanations, there are some kinds of analogies that are better than others. Teaching materials must be devised that permit students to investigate the effectiveness of their explanations and reasonings. Continuous reinforcement of appropriate analogies and metaphors in pupils' ongoing learning is recommended.

CONCLUSION

This article examines the issue of science education reform within the context of the large-scale NSTA project on **Scope, Sequence, and Coordination of Secondary School Science** (**SS&C**) from the viewpoint of a chemical educator concerned with the fact that school students apparently perceive two kinds of science: one for science class and one for everyday life. Students develop their correct or incorrect conceptual schemas of scientific events and are unable to then integrate the principles taught in class with their own experiences. Research documenting this fact is particularly evident with the concept of the basic building block of matter - the atom. When students are queried about physical and chemical phenomena they rarely offer explanations at the atomic level.

After examining the **Content Core** and Chemistry Sequence 6-12 and its proposed integration with the other science disciplines, and the misconceptions research within chemical education, it is clear that at present the SS&C initiatives lack the constructivist research base to guide its reforms. The proposed chemistry sequence is heavily laden with too many topics which are questionably sequenced, and there is no mention in the descriptives of what are and how to incorporate students' misconceptions into classroom instruction of chemistry.

The research within the discipline of chemical education concerned with identifying and classifying students' misconceptions is already rich enough to offer insights into science curriculum problems of how and what students learn in science. The overwhelming implication for teachers and curriculum designers is that the misconceptions of students must be addressed in curriculum and instruction so that errors of the past are not perpetuated in the science classroom, today. The ultimate goal of the SS&C project should not be "..science learning for all students that is interesting, relevant, challenging, and personally rewarding" (NSTA, 1992). It must include more than this; science learning should also be accurate.

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