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ABSTRACT

Living by Chemistry (LBC) is a high school curriculum project that proposes framing the "big ideas" of chemistry to provide developmental cohesion across the curriculum and promote conceptual understanding. The proposed framework, called "perspectives of Chemists," is intended to allow measurement of individual conceptual change in chemistry over time, in order to inform on the patterns and characteristics of the conceptual "change space" in the domain. The framework is based on integrating conceptual change theory with National and California State Science Standards, expert opinion, interviews with teachers, surveys of topics in high school chemistry, textbooks, and classroom observations of students. The resulting "frame" was tested and further developed in 2 small pilot studies with high school students in which student task responses were analyzed for progressions of student understanding, calibrated with item response theory measurement models, and mapped to proposed conceptual models of chemistry. Results are being incorporated into curriculum design efforts in a design experiment model of informing theory and practice concurrently. A larger initial field study at the secondary level is currently underway, with plans for further exploration of the framework at the university level. (Contains 2 figures and 27 references.) (SLD)

Perspective of a Chemist:
A Framework to Promote Conceptual Understanding of Chemistry

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Perspectives of Chemists: A framework to promote conceptual understanding of chemistry

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Abstract: Living by Chemistry (LBC) is a high school chemistry curriculum project that proposes framing the "big ideas" of chemistry to provide developmental cohesion across the curriculum and promote conceptual understanding. The proposed framework, called *Perspectives of Chemists*, is intended to allow measurement of individual conceptual change in chemistry over time, in order to inform on the patterns and characteristics of the conceptual "change space" in the domain. The framework is based on integrating conceptual change theory with National and California State Science Standards, expert opinion, interviews with teachers, surveys of topics in high school chemistry textbooks, and classroom observations of students. The resulting "frame" was tested and further developed in two small pilot studies, in which student task responses were analyzed for progressions of student understanding, calibrated with item response theory measurement models, and mapped to proposed conceptual models of chemistry. Results of the study are being incorporated into curriculum design efforts in a design experiment model of informing theory and practice concurrently. A larger initial field study at the secondary level is currently underway, with plans for further exploration of the framework at the university level as part of the new UC Berkeley ChemQuery project.

Need for improved conceptual change understanding in chemistry

The National Standards and recent curriculum reform efforts have called for a shift in the emphasis of science education from memorization of facts and procedures to a deeper understanding of the subject matter. Yet, typical chemistry instructional organization does not promote conceptual understanding in most students (Hesse & Anderson, 1992; Bodner, 1991; Driver 1994). Instead much of current chemistry instruction focuses on covering a breadth of topics without a consistent emphasis on integrating across concepts. For example, a typical high school chemistry course might group learning into a dozen or more separate concepts, such as stoichiometry, atoms and elements, the periodic table, chemical bonding, molecular structure, ideal and real gases, acid-base equilibrium, solubility, oxidation-reduction reactions, thermochemistry, chemical kinetics and thermodynamics. Students are taught many discrete knowledge pieces without an emphasis on coordinating this knowledge into a functional whole. The focus of instruction becomes fragmented acquisition of facts and algorithms rather than development of an integrated knowledge structure. The effect is that students who can correctly write a balanced chemical reaction for combustion are unlikely to be able to answer the question:

> "When a house burns to the ground and only a few pieces of charred wood and ashes are left, what happens to the rest of the mass of the house? (AAAS Project 2061 conference 2001)."

Furthermore if "the goal of chemistry instruction is to have students think about and solve conceptual problems as well as algorithmic problems then the approach to chemistry instruction must change" (Phelps, 1996).

Discoveries in cognitive research run contrary to the traditional transmission model of instruction and assessments found in many chemistry classrooms. Rather than "empty vessels" to be filled with information, students actively construct their understanding from prior experience as well as instructional treatments. However, chemistry education has incorporated little of this cognitive theory (Samarapungavan & Robinson, 2001). The underlying assumption in chemistry education has been that problem solving implies understanding, so instruction has been procedural and algorithmic (Nurrenbern & Pickering, 1987; Phelps, 1996; Sawrey, 1990).

The purpose of the LBC project is to bring conceptual change theory into practice in the teaching and learning of chemistry. However, theories of instruction under such a conceptual change model need to be based on theories of learning describing how the learner achieves conceptual understanding in this domain. Understanding the patterns by which concepts, experience, representations, ontological categorization, epistemological beliefs, and strategies (Smith, diSessa, & Roschelle, 1994; Strike and Posner, 1992), among other conceptual change mechanisms, interact to generate a working knowledge structure is a daunting task. One piece of this understanding, however, is to become familiar with common patterns of knowledge accumulation and organization in the learning of chemistry, as described within a theory of conceptual change. To this end, the LBC project has used observational studies and measures on longitudinal task assessments to refine the development of an organizing framework, called *Perspectives of Chemists*, that defines core chemistry concepts and emphasizes the integration and coordination of students' emerging chemistry knowledge.

Overview of the *Perspectives of Chemists* framework development

The main purpose of the *Perspectives* is to provide a coherent assessment frame, specified by a set of progress variables, that mediate between the level of detail in secondary science curricula in chemistry and the contents of applicable standards documents. The multidimensional construct allows mapping of individual student performance to reveal a picture of conceptual change in the domain over time. Pilot studies in 2000 and 2001 showed promise for the first dimension of the *Perspectives* as a measurable variable, explored and calibrated using IRT and latent variable analysis techniques. Studies also indicated where framework revisions were necessary in the second dimension. A larger initial field student with 400 students in six schools utilizing the revised framework is currently underway, for completion in June and analysis over the summer.

The focus of the framework is to describe the progression of student understanding, in terms of research in cognition and in chemistry education, and to propose an interpretation of how conceptual understanding develops and changes. Since the LBC goal is to develop an effective curriculum to improve student learning, the *Perspectives* are designed to organize the overarching ideas of the discipline while simultaneously constructing an instrument for measuring the values of these variables for individual students. Thus, the LBC framework emphasizes the progression of understanding as students build explanatory models of chemistry through reasoning, developing from novice to more expert conceptions. Moreover, this framework provides the foundation for reliable and valid measurement of student progress in understanding chemistry. Brown (1992) describes this as attempting to "assess conceptual change in situ." Engineering innovative educational environments while simultaneously conducting experimental studies of these innovations is a key design experiment method (Brown, 1992), used with the aim of contributing to a theory of learning while simultaneously contributing to practice.

Philosophy/Development of the *Perspectives of Chemists* framework

The LBC framework is built on the theoretical conception that the field of chemistry can be largely grouped into three core conceptions, or scientific models: matter, change and energy. The proposed framework is referred to as the *Perspectives of Chemists*. The purpose in framing the "big ideas" of chemistry is to provide developmental cohesion and promote conceptual understanding based on the assumption that a conceptual organizing framework lends meaning to facts and algorithms. Furthermore, the LBC framework is designed to emphasize the construction of understanding to aid students in knowledge integration, and to create curriculum that supports continuity of student thinking. Implicit to this model is the assumption that conceptual understanding will support the learning of algorithms and chemical definitions (Nurrenbern & Pickering, 1987). Therefore, the Perspectives are designed to provide a coherent "frame" that mediate between the level of detail in secondary science curricula and the contents of applicable standards documents. Furthermore,

The *Perspectives of Chemists* framework currently consists of three sets of progress variables along student conceptual change can be measured and curriculum can be arranged to best suit mastery learning. Each variable set represents a single "big idea," or major model used by chemists to understand chemical behavior and properties. The framework hypothesizes that a rich understanding of these three ideas, and the interactions and relationships among them, is sufficient for a strong basis of conceptual understanding through at least the high school level of general chemistry studies. Furthermore the Perspectives provide a theoretical basis for the development of an assessment tool to measure whether conceptual change has occurred.

Development of the LBC assessment has focused on the adaptation and refinement of the framework to a measurable construct using item response theory (IRT) psychometric models. (Wilson & Sloane, 2000) Therefore, the LBC assessment tasks are built to measure where each student stands on each set of variables over time, and are calibrated with psychometric models to yield a technique to track progress of individual student conceptual change. Change in student understanding is tracked through an n-dimensional space — hereinafter called a "conceptual change space" — composed of one dimension along each variable. The overall space represents theoretical relationships among the major chemistry models relied upon in the chemist's view of the world, thus the name of "Perspectives of Chemists" for the framework. Moreover, Standards-based measures and other key signposts used traditionally in chemistry assessment, as well as further measures developed in LBC design experiments, are specified within the variable structure, and thus can become manifest observables within the n-dimensional change space. This provides a method to capture traditional and standards-based measures within the framework, while allowing for the specification of additional observables as the change space is explored and conceptual change in chemistry is further understood.

The *Perspectives* dimensions are calibrated and their fit, validity and reliability are estimated with the use of item response theory (IRT) psychometric models. Developed and refined over the last several decades, these models have been used extensively in psychology to track attitudinal change over time, and are sometimes used to calibrate academic performance measures in other settings. However, the models have been little employed to directly obtain measures of conceptual change in specific domains, and we are unaware of prior use in the tracking of chemistry conceptual change.

The overall idea of considering individual conceptual change patterns within a larger network of domain-specific concept relationships, however, has been previously discussed in the cognitive science and education literature. David Hawkins, a cognitive scientist and philosopher of science as well as science educator, offered a description as early as 1970. While this was well before psychometric models and the necessary underlying computational algorithms were available to attempt measurement, he encapsulates the essence of the idea:

> "The tree remains my symbol for the patterns of individual learning and searching while the network, the public map, represents some ultimate order, never fully achieved, in that which is there to be learned.... In this sense a network will accommodate many trees that can be cut out of it, yours marked in blue crayon and mine marked in green. The network itself symbolizes in my thinking the real order and connection of the world which each of us explores along the forking paths of his own experience, meeting now and again for conversation, fitting the maps of our separate trees together within that common order." (Hawkins, 1970)

Details of the *Perspectives of Chemists* framework strands

The three sets of Perspectives variables, or strands, describe chemistry models and views regarding three "big ideas" in chemistry: matter, change and energy, respectively. The matter strand is concerned with describing atomic and molecular views of matter, as well as measurements and model refinement regarding matter. Change involves kinetic views of change and the conservation of matter during chemical change. Energy is concerned with the network of relationships in the conservation and quantization of energy. An initial hypothetical framework of strands developed in 2000 was refined into the current iteration after two pilot studies supported the measurement potential of a matter strand structured along the suggested lines but showed necessary changes in the initial representation of the second and third strands. A field test now underway is, among various objectives, investigating the fit, reliability, validity and overall efficacy of the current framework structure as a measurement tool.

Each strand consists of two progress variables, one reflecting a macroscopic, or large scale, observable, view of the concept embedded in the strand — matter, change or energy — and the other reflecting a microscopic, or molecular view. It should be noted that early formulations of the Perspectives did not contain this dual view. However data collection in the classroom and task development made evident the necessity for the distinction, and it was realized that chemists actually do operate with two different perspectives within each strand. It is the LBC recommendation that these views should be clarified and made more explicit in the education and assessment of students for effective conceptual change to be achieved in chemistry. Further support for these dual views comes from the education literature, which describes the confusion of macroscopic and microscopic properties as a key source of misconceptions in chemistry (Hesse & Anderson, 1992; Ben-Zvi, Eylon & Silverstein, 1986; Griffiths & Preston, 1992; Brook, Briggs, & Driver, 1984, as cited in Griffiths & Preston, 1992). Ben-Zvi and colleagues described student attempts to make "the transition from one molecule to many molecules" in the understanding of chemical properties as extremely difficult." They found that students attributed properties that only exist at the macroscopic level to individual atoms and molecules. Brook, Briggs and Driver subsequently concurred, showing that students tend to transfer changes in macroscopic properties to the microscopic level, such as suggesting "that particles can become hot or cold, or even melt." Krnel et al (Krnel, Watson & Glazer, 1998) conclude that students transfer incorrect concepts regarding properties of matter to the micro world of particles so that individual particles (i.e. molecules, atoms and compounds) are described with the same properties as matter. LBC findings bolster these contentions.

The dual views of each Perspective variable are summarized in Figure 1, with additional detail in Figure 1b. Figure 1b is intended to approach the level of detail needed to place traditional topics within the *Perspectives* framework.

It is not the purpose of this paper to detail the placement of each chemical concept along each variable at this time, as this information will be included with the publication of data from field trials. However, the derivation of the general levels will be described for those interested in this framework or who would like to pursue the development of analogous tools to measure change spaces in other domains.

Details of the *Perspectives of Chemists* framework levels

Perhaps the most unusual concept to understand regarding the level specification in the Perspectives framework is that IRT tools allow the levels to be empirically derived. That is, while hypotheses can be generated regarding what conceptual change levels might theoretically consist of in a domain, IRT tools allow for such hypotheses to be confirmed or rejected based on actual student data, and for the generation of new levels based on empirical data alone, within a given framework of strands. This allows for a mechanism to explore conceptual change theory within a domain. The structure of levels in the first strand of the Perspectives framework has been supported by preliminary IRT estimates (Scalise, unpublished, 2000), while preliminary measures on strand two suggested changes currently in place (Claesgens, unpublished, 2001). A larger field trial with 400 students in 4 schools is currently underway, and will help inform further development of the strands.

While strand levels shown in Figure 1 range from 1 to 6, it should be noted that the curriculum standards for high school chemistry are confined, for the most part, to levels 1 to 3. These levels are discussed below. For explanatory purposes, a single assessment item measuring along the first matter strand will be used as an example, with actual student answers at each level given. The example item compares two chemicals that have the same molecular formula but different properties, and asks students to account for the differences:

> You are given two liquids. One of the solutions is butyric acid with a molecular formula of $C_4H_8O_2$. The other solution is ethyl acetate with the molecular formula $C_4H_8O_2$. Both of the solutions have the same molecular formulas, but butyric acid smells bad and putrid while ethyl acetate smells good and sweet. Explain why you think these two solutions smell differently.

Level 1 of the Framework: Describing and using reasoning without chemistry

Fundamental to the theory of conceptual change is that students come to a new area of learning bringing their prior ideas, In terms of chemistry these prior ideas have to do with experiences of matter and change from their everyday lives — which are sometimes appropriate and at other times described as misconceptions. Moreover these ideas affect student understanding. Misconceptions are described as "students' efforts to extend existing useful conceptions to instructional contexts" (Smith, diSessa & Roschelle, 1993) outside the scope of those concepts. Vosniadou (Vosniadou & Brewer, 1992) explains that students try to "reconcile" everyday experience with instructional information. However within the LBC framework, misconceptions are viewed as an early level of progression in student understanding rather than as simply impediments to conceptual understanding. By contrast, in traditional views of chemistry education outside of the conceptual change framework, reasoning attempts that resort to logic when molecular chemistry concepts should be employed — or in which molecular concepts are fundamentally misapplied as misconceptions—would simply be viewed as wrong.

This first level acknowledges that without domain knowledge students will focus on surface features to problem solve [Chi cited in Bransford et al (1991)]. Hesse and Anderson(1992) found that students regularly used commonsense thinking in place of scientific concepts and that scientific explanations involved little more than the ability to "talk fancy." In addition, studies acknowledge that misconceptions in chemistry develop based on "immediate perceptual clues" (Krnel, Watson & Glazer, 1998). Students tend to be descriptive and define matter in terms of its observable properties, i.e. hot/cold, hard/soft, color, and when the matter changes it is considered different or new because it has different properties. For example, hot air is just that, hot air. It is not air that can be hot or cold because each is perceived as a different substance (Krnel, Watson & Glazer, 1998).

LBC analysis shows this initial level of student conception or understanding falls into three general categories, which by preliminary IRT analysis can be scaled from low to high with lowest closest to a zero answer and the highest closest to a level 2 answer. The first category of answer observed at the 1 level (this category is scored 1-) is a simple macroscopic observation, usually regarding a piece of data provided in the task or on some component of the item stem. The second type of answer (scored 1) uses logical patterning and comparative reasoning in addition to observations to generate an answer, but employs no chemistry. The third category (scored 1+) seeks to use chemistry, but employs one of a variety of fundamental misconceptions, thereby skewing the answer in an entirely incorrect direction. Examples of responses at each level appear in Figure 2.

Much of the reasoning seen in level 1 LBC responses might be considered sound logic, except that students are operating without domain knowledge and the specific understandings of chemistry known to chemists. Far from an indictment of student ability to reason generally, LBC findings thus far concur with Abraham et al (Abraham, Grzybowski, Renner & Marek), who remark on "how clever and resourceful students are in utilizing what information they do have in order to try and develop concepts to explain phenomena." Where this information is inadequate or non-normative, however, student reasoning alone is not a sufficient knowledge structure for productive problem solving in chemistry. The issue is not that novices cannot reason, but just that they do not reason like chemists, or with the domain knowledge of chemists (Samarapungavan & Robinson, 2001). This is especially significant in chemistry where students develop fewer models of understanding from experience and are more likely to rely on instruction.

Furthermore, it should be noted that while misconceptions employing chemistry may seem to rank lower in conceptual understanding than logical reasoning that does not employ chemistry, empirical results of the IRT analysis so far show that students employing misconceptions on one item have a higher probability of achieving a level 2 normatively correct chemistry answer on other items than do those using logic without attempts to employ chemistry. If this finding should hold up under further analysis, it would be an interesting addition to the misconception literature, and to the conceptual change relationship of misconceptions to normative conceptions. A possible explanation might concern epistemological beliefs, in that those students who believe they must go beyond generalized logic and resort to molecular chemistry concepts, even if used incorrectly, are closer to normative conceptions in chemistry than those who are not yet ready to attempt to use the tools of the domain.

Level 2 of the Framework: Representing with simple scientific descriptions

In the next progression of understanding, students begin extending experience and logical reasoning to include accurate chemistry-specific domain knowledge. In the conceptual framework, this is when students begin to employ definitions, terms, and principles with which they will later reason and negotiate meaning. More importantly, this is where most theories of knowledge and instruction tend to stop in chemistry. The assumption in chemistry education has been that knowledge of chemistry terms equals correct explanatory models of understanding. Yet, both Sumfleth (1988) and Yarroch (1985) found that students possess a basic knowledge of chemical terms, but they are unable to establish the correlation between them and apply their knowledge. Sumfleth (1988) concludes that "students have a basic knowledge of terms but do not recognize relationships and are unable to apply their knowledge." This is an excellent summary of student knowledge at level 2 of the LBC framework.

At level 2, students are concerned with learning the "language" and representations of the domain of chemistry and are introduced to the ontological categories and epistemological beliefs that fall within the domain of chemistry. Students may focus on a single aspect of correct information in their explanations but may not have developed more complete explanatory models to relate to the terms and language.

At Level 2, student responses are one dimensional, in that they are simple explanations in the form of definitions, algorithms or representations that stand alone to account for an observation or physical behavior. Such responses must follow normative chemistry models for the response to fall into level 2, but at 2- are partially complete or correct and gain normativity and accuracy as responses progress in score toward level 3. Student responses to the example question show in Figure 3.

Level 3 of the Framework: Relating, using patterns and equations

Chemical education research on student misconceptions shows that students who fail to sufficiently or accurately relate concepts develop incomplete explanatory models. The argument here is that confusion can result from student combining chemical representations, experience, and domain-specific reasoning, resulting in limited, misconceived, and/or naïve models of understanding.Coordinating and relating developing knowledge in chemistry becomes critical to move to the next level of understanding described in the LBC construct. Niaz and Lawson (1985) argue that without generalizable models of understanding, students choose to memorize rules instead, limiting their understanding to the 2 level of the *Perspectives*. Students need a base of domain knowledge before integration and coordination of the knowledge develops into understanding (Metz, 1995). So as they move toward level 3, students should be developing a foundation of domain knowledge so that they can begin to reason like chemists by relating terms to conceptual models of understanding in chemistry, rather than simply memorizing algorithms and terms.

"Relating" terms, experience and concepts explicitly emphasizes reasoning with domain specific knowledge, the characteristic of level 3. Early in the LBC design experiment study, it became apparent that level three topics are often traditionally taught at the beginning of the year, much too soon to expect a reasonable base of domain specific understanding at a level two representational level. It became immensely clear that instructions in topics such as density and dissolving were lost on most students at the conceptual level, and needed to be moved later in the curriculum. One LBC finding thus far is that most students need substantial domain-specific knowledge at the representation level before they could begin reasoning effectively in a relational way. This may be one of the more serious impediments to conceptual understanding in chemistry to become apparent so far in LBC studies. LBC curriculum modules have been adjusted accordingly, to allow students a smoother transition through levels 1, 2 and 3.

Students need to examine and connect ideas to derive meaning in order to move to level 3, which appears to be a difficult transition although little data has been collected at this level as of yet as few high school students studied so far achieve the transition. Extremely small collections of informant data at the university level show that first-year chemistry students may not have effectively made this transition either, even after prior high school chemistry and some period of instruction at the college level. Note that investigations at the university level using the Perspectives framework are being launched as part of a new UC Berkeley project called ChemQuery, supported by the National Science Foundation.

Although little empirical data exists to support level 3 yet, there are many ways in which it can be seen that students need to relate concepts at this level and provides a theoretical explanation of student misconceptions—they do not have their domain knowledge well coordinated into normative explanatory models. The knowledge coordination and integration is multi-fold. For example, one type of relational integration is between students' experience and the explanatory models or concepts of chemistry.

Another type of integration incorporates the chemical notation to these explanatory models of chemistry. And still another type of integration is the integration of the mathematical formulas and algorithms to the chemical notation, concepts and macroscopic explanations. Therefore, conceptual understanding becomes a web of intricate connections (diSessa & Sherrin, 1998). Before the intricacies are understood, students are using multiple aspects of information available but do not know enough to reason through all the various configurations resulting in fragments of relational understanding (see relational level of SOLO taxonomy, Biggs & Collis, 1982, which also reflects this partially relational progression to more fully relational). The LBC assessment framework will let us measure which of these relational aspects are constraining students' conceptual understanding.

Evidence and Implications

In Fall 2000 and 2001, LBC conducted small empirical pilot studies in local high schools in which extensive observational studies already were taking place with LBC curriculum materials (Scalise, 2000; Claesgens, 2001). The pilot studies were an attempt to determine if student progress of understanding in chemistry could be mapped with IRT psychometric tools, and to test the theoretical construct of the first two strands of the original *Perspectives* framework. These studies revealed that the first matter strand showed promise within a psychometric framework, while the second strand needed both revision and additional cases to make reliability, validity and fit determinations. This paper will describe the analysis of the first strand. Further analysis on this and some of the remaining strands will be available this summer, when a larger initial field study is complete.

Strand 1 Analysis

Design of the assessment instruments included the following: 1) creation of assessment items to measure student understanding of the first Perspective of Chemists, 2) collection of rounds of informant data to validate the items, 3) review of the assessment instrument by a panel of educational measurement experts, 4) development of a scoring rubric to analyze data on student responses, 5) analysis of the validity and reliability of the instrument and rubric.

The pilot test of the assessment design on strand d1 was conducted in classrooms in Fall 2000. Participants included105 students from six trial classrooms in San Francisco and Berkeley public schools. Students from the ethnically and racially diverse schools ranged in age from 14 to 18, and were enrolled in college preparatory or conceptual chemistry courses. A pretest/posttest format was used, and tracked student conceptual change over s six-week period. The pretest consisted of open-ended questions followed by a series of posttests that included both open-ended and multiple-choice questions. The posttests consisted of three separate assessments over six weeks that were administered after students were presented with the relevant portion of the curriculum. Responses collected from the instrument trials were scored, coded, and analyzed with the Quest Interactive Test Analysis System, using a Rasch partial credit model estimation. The

Rasch analysis provided item estimates, case estimates, fit statistics, other test statistics and a variety of reliability indices.

The results from the pilot study measured sizable and statistically significant student learning gains, using the Living by Chemistry materials, within the first Perspective of Chemistry. Overall, students showed a significant mean gain in person performance estimates from pre-test to post-test ($t=-14.1$, $p<.0005$). Figure 4 shows gains by students with low, medium, and high pretest Rasch person performance estimates. Total gain was greatest for students with the lowest pretest scores. Findings showed that the thinking of the average student is transitioning from a continuous view of matter (Level 1) to a preliminary stage of understanding of the atomic view of matter (Level 2). This is a key piece of information for chemistry teachers and curriculum developers, and suggests that teaching materials should be designed to address this level of understanding at this point in teaching chemistry, rather than focusing on student proficiency in representing and explaining matter in terms of its particulate nature, as is the more traditional approach.

Perhaps even more importantly, however, the IRT analysis showed that the single variable by which students were measured held up as a continuum along which conceptual change could be measured. Item construct mapping showing partial credit model results shows in Figure 5, with person estimates on left and item estimates on right. Reliability was fairly high (Cronbach's alpha >.8) and tests of validity showed that the expected item difficulty estimates matched the construct well across all assessment tasks. Even where tasks varied significantly in previous student exposure, similar estimates of student level were achieved across items, with the exception of only a few sublevels (see item estimates marked in red, which are slightly out of expected level). More than 90 percent of students showed good fit across items and measurement error was low across items (averaging .3 logit, except at extremes of measurement where few cases were available). Main levels were distinct within measurement error, and a definite, consistent pattern could be seen across items and students. (For further details of this pilot study, see Scalise, 2000).

Future directions

While the successful use of such a construct models on one variable across a small sample of students does not prove that a hypothetical conceptual change space in chemistry can be measured according to the *Perspectives* framework, the promising data obtained are leading to further studies at both the secondary and university level with more students and over more strands. A study of 400 students in 6 schools is currently underway, with results expected this summer.

Conclusion

Fundamental to achieving the goal of moving the model of instruction in the high school classroom toward supporting students' construction of conceptual understanding is a better understanding of that construction. The preliminary pilot studies indicate that it may be possible to create a generalizable conceptual framework to make explicit the relationship of the "big ideas" and main conceptual models in chemistry. A combination of a design experiment model for curriculum development, classroom observational studies and expert commentary from content and education experts, teachers and the literature made possible the initial conception of the *Perspectives* framework described in this paper. In a small pilot study, learning within the first *Perspective* was shown to be measurable as a progressive continuum from a naive to more complete understanding of the abstract conceptual model. Student learning within this model is conceived not simply as a matter of acquiring more knowledge and skills, but as a conceptual change progress towards higher levels of competence as new knowledge is linked to existing knowledge, and deeper understandings are developed from and take the place of earlier understandings. This is in contrast to a traditionally much more fragmented view of the discipline in which students often fail to integrate their knowledge, and are unable to "reason like a chemist" when problem solving.

Moreover, the *Perspective* framework might make it possible to better explore patterns of conceptual change in chemistry using new tools, and to explore the underlying "change space" in chemistry. Further LBC and ChemQuery work will analyze integration of conceptual understanding across the three Perspectives variable sets. Further determinations will be made on whether the theoretical construct supports student conceptual understanding of chemistry while simultaneously exploring the conceptual change space in chemistry and providing a framework for future curriculum development and assessment design. For example, additional research efforts include whether certain misconceptions and paths of conceptual change are more or less resistant to instruction, and might explain some of the puzzling evidence in the literature describing the difficulty of achieving conceptual change in this domain. Ultimately, it is hoped that the *Perspectives* framework will prove to be an additional useful tool in this exploration of conceptual change in the domain of chemistry.

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Figure 1 and 1b. The dual views of each *Perspective* variable are summarized in Figure 1, with additional detail in Figure 1b. (See attached "Perspectives" for these figures.)

Figure 2. Examples of actual student responses at *Perspectives* Level 1.

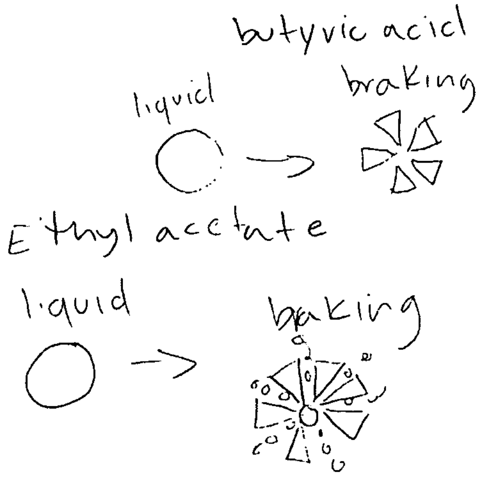
Level One: Describing Properties of Matter	1-	Response: If they have the same formula, how can they be different? Analysis: Student makes one macroscopic observation by noting that the molecular formulas in the problem setup are the same.
	1	Response: I think there could be a lot of different reasons as to why the two solutions smell differently. One could be that they're different ages, and one has gone bad or is older which changed the smell. Another reason could be that one is cold and one is hot. Response: Using chemistry theories, I don't have the faintest idea, but using common knowledge I will say that the producers of the ethyl products add smell to them so that you can tell them apart. Response: Just because they have the same molecular formula doesn't mean they are the same substance. Like different races of people: black people, white people. Maybe made of the same stuff but look different. Analysis: These students use ideas about phenomena they are familiar with from their experience combined with logic/comparative skills to generate a reasonable answer, but do not employ molecular chemistry concepts.
	1+	Response: "Maybe the structure is the same but when it breaks into different little pieces and changes from liquid into gas they have a different structure in the center and have a different reaction with the air. (Shows drawing:)  Analysis: This answer acknowledges that chemical principles or concepts can be used to explain phenomena. Attempts are made to employ chemical concepts based on a "perceived" but incorrect understanding of the chemistry involved.

Figure 3.

Level Two: Representing Matter	2-	Response: "I think these two solutions smell different is because one chemical is an acid and most acids smell bad and putrid while the ethyl acetate smells good and sweet because its solution name ends with "ate" and that usually has a good sweet smell." Analysis: This response correctly cites evidence for the difference in smells between the two chemicals, appropriately using smell combinatorial patterns taught in class and chemical naming conventions, but does not explain the root cause as the difference in molecular structure between the two chemicals.
	2	Response: "They smell differently b/c even though they have the same molecular formula, they have different structural formulas with different arrangements and patterns." Response: "Butyric acid smell bad. It's an acid and even though they have the same molecular formula but they structure differently." Both responses appropriately cite the principle that molecules with the same formula can have different structures, or arrangements of atoms within the structure described by the formula. However the first answer shows no attempt and the second answer shows an incomplete attempt to use such principles to describe the simple molecules given in the problem setup.
	2+	Response: (Begins with problem setup below, showing molecular formula of labeled butyric acid and same formula labeled ethyl acetate.) $C_4H_8O_2$ - butyric acid $C_4H_8O_2$ - ethyl acetate "The two molecules smell differently because the have different molecular structures. The butyric acid contains a carboxylic acid structure (which smells bad) and the ethyl acetate contains an ester (which smells good). We can tell which molecule will smell bad and which will smell good by studying the molecular structure and by looking at the names. Any 'ACID' ending name will smell bad and any '-ATE' ending name will smell good." Analysis: Response cites and appropriately uses the principle that molecules with the same formula can have different structures. Student correctly cites rule learned in class pertaining to smell patterns in relation to functional groups identified by chemical name, and uses this information to begin to explore simple molecules. However, student stops short of a Level Three response, which could be made by examining structure-property relationships through, for instance, presenting possible structural formulas for the two chemicals and explaining the bonding involved.

Figure 4.
Post test gains of student understanding in *Perspectives* pilot study.

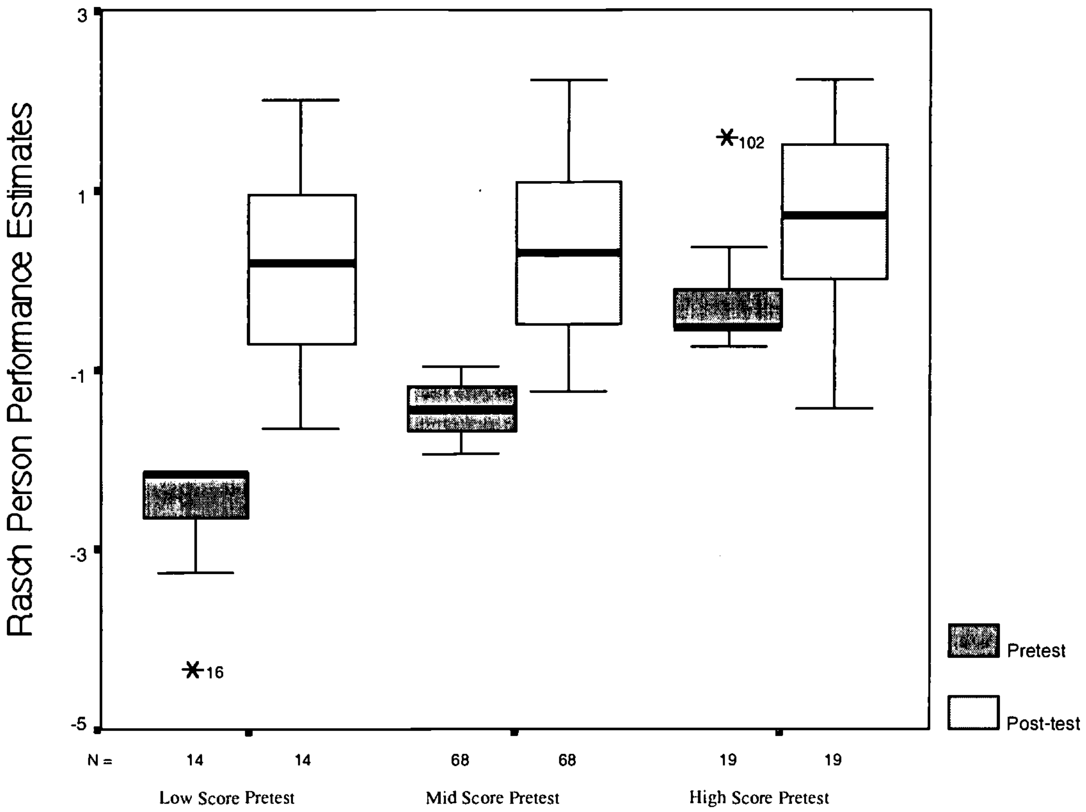


Figure 5. Item construct mapping showing partial credit model results for Perspectives pilot study, with person estimates on left and item estimates on right. See Scalise, 2000 for more detailed explanation. (Figure 5 is in the attached "LBC IRT Wright Map" file.)

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Figure 5: Item Estimates                                              07-Dec-** 07:16:22
(N = 238;L = 14;Probability=.5)         Polychotomous Items Columns 1-5, Quick √s Col. 6
------------------------------------------------------------------------------------------
  5.0                             | S      H      B     S     D      Q                Item
                                  | i      O      o     m     i      u          Difficulty
                                  | /      N      t     e     s       i              Levels
                                  | C      C      t     l     s       c
                                  |                     l     o       k
  4.0                             |              3.2+        l       √
                                  |                           v
                                  |                            e
                                  |
                                  |
                                  |                     4.2+         12.2+
  3.0                             |        2.3-
                                  |        2.2+
                                  |                           5.3-              2+/3- levels
                                  |
                           XXX    |
  2.0                             |        2.2
                          XXXX    |                                  14.2
                            XX    |
                         XXXXX    |1.2                        5.2+!!
                        XXXXXX    |              3.2         5.2                    2 level
                      XXXXXXXX    |
  1.0                      XXX    |                           5.2-
                        XXXXXX    |              3.2-
                         XXXXX    |                                  7d.2-
                   XXXXXXXXXXX    |                     4.2!!        11.2-
                     XXXXXXXXX    |                                  7c.2-,8b.2-
   .0                   XXXXXX    |
                       XXXXXXX    |                                  7a.2-,7b.2-
                   XXXXXXXXXXX    |1.2-    2.2-         4.2-         13b.2-,13c.2-  2- level
        XXXXXXXXXXXXXXXXXXXXXX    |              3.1+        5.1+   6c.1+
                         XXXXX    |        2.1+         4.1+         9.1+
                XXXXXXXXXXXXXX    |1.1+                                             1+ level
 -1.0             XXXXXXXXXXXX    |
            XXXXXXXXXXXXXXXXXX    |                                  6b.1
       XXXXXXXXXXXXXXXXXXXXXXX    |                                  13a.1
                                  |                                  6a.1
  XXXXXXXXXXXXXXXXXXXXXXXXXXXX    |                                  10.1
 -2.0             XXXXXXXXXXXX    |1.1                               8.1
                    XXXXXXXXXX    |        2.1                5.1
                                  |                     4.1                          1 level
                          XXXX    |                     4.1-
                            XX    |
                                  |1.1-           3.1!! ←-----------!!items are out of level
 -3.0                             |
                             X    |        2.1-   3.1-
                                  |
                                  |                           5.1-                  1- level
                                  |
 -4.0                             |
                                  |
                             X    |
                                  |
                                  |
                                  |
 -5.0                             |                                                0 level
```

Each X represents 1 student.

Figure 1. ChemQuery Assessment System

Perspectives of Chemists

	atomic scale	macro scale	atomic scale	macro scale	macro scale	atomic scale
6 Understanding	ATOMIC AND MOLECULAR VIEWS	MEASUREMENT AND MODEL REFINEMENT	REARRANGEMENTS OF ATOMS	CONSERVATION OF MASS	CONSERVATION OF ENERGY	QUANTIZATION OF ENERGY
5 Integrating	A and E bonding and relative reactivity	B and F models and evidence	C and A kinetics and changes in bonding	D and E stoichiometry and equilibrium	E and A, C particle and energy views	F and A spectroscopy and structure
4 Predicting	phase and composition	limitations of models	products of reaction	amounts of products	degrees of change	electronic structure
3 Relating	properties and atomic views	measured amounts of matter	change and reaction types	amount of reactants and products	energy transfer and change	color with light absorption
2 Representing	matter with chemical symbols	mass with a particulate view	change with chemical symbols	change with a conservation view	heat and temperature	energies associated with light
1 Describing	properties of matter	amounts of matter	attributes of change	changes in mass	measures of energy	light
Levels of success / **Variables**	**A** ***Visualizing matter*** Matter is composed of atoms arranged in various ways	**B** ***Measuring matter*** Mass is used to account for matter.	**C** ***Characterizing change*** Change is associated with rearrangements of atoms.	**D** ***Quantifying change*** Mass is used to keep track of change.	**E** ***Evaluating energies*** Energy transfer is used to analyze tendency for change.	**F** ***Quantizing energy*** The interaction of light with matter is used to elucidate structure.
	MATTER		**CHANGE**		**ENERGY**	

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Figure 1b. ChemQuery Assessment System
Perspectives of Chemists

6 **Understanding**	ATOMIC AND MOLECULAR VIEW	MEASUREMENT AND MODEL REFINEMENT	REARRANGEMENTS OF ATOMS	CONSERVATION OF MASS	CONSERVATION OF ENERGY	QUANTIZATION OF ENERGY
5 **Integrating** Linking various models	A and E **bonding and reactivity** advanced bonding models, nucelophiles, electrophiles	B and F **models and evidence** evidence for ideas about things we can't "observe" directly	C and A **kinetics and changes in bonding** reaction mechanisms, rate laws, activation energy	D and E **stoichiometry and equilibrium** weak acids and bases, solubility of salts and gases	E and A, C **particle and energy views** statistical mechanics, KE and temperature	F and A **spectroscopy and structure** group theory, transition probabilities
4 **Predicting** Scientific models	**phase and composition** bond strengths, intermolecular attractions, polarity	**limitations of models** examining assumptions, real vs. ideal gases,	**products of reaction** solubilities, relative acid strengths, redox potentials	**amounts of products** limiting reagents, strong acid/base titrations, % yield	**degrees of change** entropy, free energy, and equilibrium	**electronic structure** quantum model, atomic and molecular orbitals, ionization energy
3 **Relating** Patterns and equations	**properties and atomic views** octet rule, ionic bonds, covalent bonds, Lewis dot structures	**measured amounts of matter** density, grams per mole, gas laws, molarity	**change and reaction types** precipitation, acid-base, redox	**amount of reactants and products** reaction stoichiometry, gram/mole conversions, pH	**energy transfer and change** enthalpy changes, Hess' law, bond breaking	**color with light absorption** absorption and emission spectra
2 **Representing** Scientific descriptions	**matter with chemical symbols** elements, compounds, solutions, valence electrons, periodic trends	**mass with a particulate view** atoms, isotopes, mass, moles, periodic table	**change with chemical symbols** writing balanced chemical equations, physical vs. chemical change	**change with a conservation view** conservation of mass in chemical reactions	**heats and temperature** heat capacity, calorimetry, exo(endo)thermic	**energies associated with light** frequency, speed, Planck's constant
1 **Describing** Observations	**properties of matter** solids, liquids, gases, mixtures	**amounts of matter** mass, weight, volume, pressure	**attributes of change** mixing, dissolving, gas production, color change, change in form	**changes in amount** changes in mass, weight, volume	**measures of energy** temperature scales, measures of energy	**light** production of light, color
Levels of success / **Variables**	A ***Visualizing* matter** Matter is composed of atoms arranged in various ways	B ***Measuring* matter** Mass is used to account for matter.	C ***Characterizing* change** Change is associated with rearrangements of atoms.	D ***Quantifying* change** Mass is used to keep track of change.	E ***Evaluating* energies** Energy transfer is used to analyze tendency for change.	F ***Quantizing* energy** The interaction of light with matter is used to elucidate structure.

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