I. Multiple choice single answer (68% total, 4% for each)

1. Use the bond enthalpies given to estimate the heat released when 1-bromobutene, CH₃CH₂CH=CH₂, reacts with bromine to give CH₃CH₂CHBrCH₂Br. Bond enthalpies (kJ·mol⁻¹): C-H, 412; C-C, 348; C=C, 612; C-Br, 276; Br-Br, 193.
   A) 181 kJ·mol⁻¹
   B) 317 kJ·mol⁻¹
   C) 288 kJ·mol⁻¹
   D) 95 kJ·mol⁻¹
   E) 507 kJ·mol⁻¹

2. Which of the following is polar?
   A) XeF₄
   B) PCl₅
   C) ICl₄⁻
   D) SF₆
   E) IF₅

3. The structure of rubber, a polymer, is

\[
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{CH₂}
\end{array}
\begin{array}{c}
\text{CH₃} \\
\text{CH₂} \\
\text{H}
\end{array}
\end{array}

What is the formula of the monomer used to produce rubber?
   A) (CH₃)₂CCCH₃
   B) CH₃CCCH₃
   C) CH₂CCCH₂
   D) CH₂(CH₃)CHCH₂
   E) CH₃CH(CH₃)CH₂CH₃

4. In a one-dimensional particle in a box, for Ψ₄, how many nodes are predicted?
   A) 1
   B) 3
   C) 0
   D) 2
   E) 4
5. The product of the reaction of 2-butene with Cl₂ is
   A) 3,3-dichlorobutane.
   B) 2,3-dichlorobutane.
   C) butane.
   D) 2-chlorobutane.
   E) 2,2-dichlorobutane.

6. For the cell diagram
   \[ \text{Pt} | \text{H}_2(\text{g}), \text{H}^+(\text{aq}) \mid \text{Cu}^{2+}(\text{aq}) \mid \text{Cu(s)} \]
which reaction occurs at the anode?
   A) \( \text{Cu(s)} \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \)
   B) \( 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) \)
   C) \( 2\text{H}^+(\text{aq}) + \text{Cu(s)} \rightarrow \text{H}_2(\text{g}) + \text{Cu}^{2+}(\text{aq}) \)
   D) \( \text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu(s)} \)
   E) \( \text{H}_2(\text{g}) \rightarrow 2\text{H}^+(\text{aq}) + 2\text{e}^- \)

7. For the compounds below, which statement is true?

   ![Image of compounds 1 and 2]

   A) Compound 1 is chiral.
   B) Compounds 1 and 2 are chiral.
   C) Compounds 1 and 2 are geometric isomers.
   D) Compounds 1 and 2 are identical.

8. All the following can have the ground-state electron configuration \([\text{Xe}]4f^{14}5d^0\) except
   A) \( \text{Pb}^{2+} \).
   B) \( \text{Hg}^{2+} \).
   C) \( \text{Bi}^{3+} \).
   D) \( \text{Tl}^+ \).
   E) \( \text{Au}^+ \).
9. Which of the following is likely to have the largest exothermic hydration enthalpy?
   A) Sr^{2+}
   B) Na^{+}
   C) Mg^{2+}
   D) Ca^{2+}
   E) Li^{+}

10. Which one of the following statements is true?
   A) Labile is a term that refers to the thermodynamic tendency of a substance to decompose.
   B) Spontaneous reactions always have $\Delta G^o > 0$.
   C) Spontaneous reactions always have $\Delta H^o < 0$.
   D) Spontaneous reactions always have $\Delta S^o > 0$.
   E) A thermodynamically stable compound is a compound with a negative standard free energy of formation.

11. Calculate $\Delta S^o_{\text{react}}$ at 298 K for the reaction
    $$\text{H}_2(\text{g}) + \text{F}_2(\text{g}) \rightarrow 2\text{HF}(\text{g})$$
    $\Delta H^o = -546 \text{ kJ/mol}$, $\Delta S^o = +14.1 \text{ J/Kmol}$
    A) $+14.1 \text{ J/Kmol}$
    B) $+1820 \text{ J/Kmol}$
    C) $+1830 \text{ J/Kmol}$
    D) $-1830 \text{ J/Kmol}$
    E) $-14.1 \text{ J/Kmol}$

12. The bond order of $\text{N}_2^{2+}$ is
    A) 2.5.
    B) 1.
    C) 2.
    D) 1.5.
    E) 3.
13. Calculate the lattice enthalpy of calcium oxide from the following data.
   enthalpy of formation of Ca(g): +178 kJ·mol$^{-1}$
   first ionization energy of Ca(g): +590 kJ·mol$^{-1}$
   second ionization energy of Ca(g): +1150 kJ·mol$^{-1}$
   enthalpy of formation of O(g): +249 kJ·mol$^{-1}$
   first electron affinity of O(g): +141 ($\Delta H = -141$) kJ·mol$^{-1}$
   second electron affinity of O(g): -844 ($\Delta H = +844$) kJ·mol$^{-1}$
   enthalpy of formation of CaO(s): -635 kJ·mol$^{-1}$
   A) 1817 kJ·mol$^{-1}$
   B) 1391 kJ·mol$^{-1}$
   C) 2235 kJ·mol$^{-1}$
   D) 3754 kJ·mol$^{-1}$
   E) 3505 kJ·mol$^{-1}$

14. Which of the compounds below has bonds with the most covalent character?
   A) NaCl
   B) LiCl
   C) CaCl$_2$
   D) BeCl$_2$
   E) MgCl$_2$

15. Consider the reaction
   $$2\text{CuBr}_2(\text{s}) \rightarrow 2\text{CuBr}(\text{s}) + \text{Br}_2(\text{g})$$
   If the equilibrium vapor pressure of Br$_2$(g) is $1.43 \times 10^{-5}$ Torr at 298 K, what is $\Delta G$ at this temperature when Br$_2$(g) is produced at a pressure of $7.50 \times 10^{-7}$ Torr?
   A) -7.31 kJ
   B) 7.31 kJ
   C) 39.9 kJ
   D) -3.17 kJ
   E) -4.15 kJ

16. What are all the intermolecular forces that are responsible for the existence of the molecular solid oxalic acid, H$_2$C$_2$O$_4$?
   A) dipole-dipole, London forces, and hydrogen bonding
   B) dipole-dipole and London forces
   C) hydrogen bonding and dipole-dipole
   D) London forces
   E) dipole-dipole and ion-ion
17. How many unpaired electrons can be predicted for an iron(II) complex when the complex is tetrahedral?
   A) 1
   B) 2
   C) 3
   D) 4
   E) 5

II. Short answer questions: (12% total)
1. A new substance developed in a laboratory has the following properties: normal melting point, 38.6°C; normal boiling point 177°C; triple point 200 Torr and 83.7°C
   1.1 Sketch the approximate phase diagram. (2%)
   1.2 Please decide which phase is more dense, liquid or solid, and explain it. (4%)

2. Arrange the anion Cl-, Br-, N3- and O2- in order of increasing polarizability (2%) and explain it (4%).
III. 請依據下面的研究報告回答下列問題:
1. 該研究的目的為何? (5%)
2. 該研究的資料來源與搜集過程(研究設計)為何? (5%)
3. 本研究的發現為何? (5%)
4. 本研究對於化學的教學與學習啟示為何? (5%)

Students' predictions about the sensory properties of chemical compounds: Additive versus emergent frameworks
Science Education, vol. 92, pp. 96-114 (2008)

ABSTRACT: We investigated general chemistry students’ intuitive ideas about the expected properties of the products of a chemical reaction. In particular, we analyzed college chemistry students’ predictions about the color, smell, and taste of the products of chemical reactions represented at the molecular level. The study was designed to explore the extent to which novice learners intuitively use an additive framework to predict the properties of the product, rather than an approach that recognizes the emergent nature of the properties of chemical compounds. To this end, we used a mixed-methods research approach based on answers to multiple-choice questions and individual interviews with students enrolled in the first year of an introductory general chemistry course for science and engineering majors. Our results indicate that most students at this level rely on an additive heuristic to predict the properties of chemical compounds, overlooking the possibility of emergent properties resulting from the interaction of the atoms that compose the system. Chemistry instructors and chemical educators thus need to intentionally design learning opportunities for students to recognize and differentiate additive and emergent properties in a variety of contexts. © 2007 Wiley Periodicals, Inc. Sci Ed 92:96-114, 2008

METHODOLOGY
In this study, we explored college general chemistry students’ predictions about the color, smell, and taste of chemical compounds resulting from the chemical reaction between two substances with specified properties. We specifically targeted student thinking based on microscopic (particulate) representations of chemical systems. This investigation was guided by the following research question:

What conceptual framework, additive versus emergent, is most commonly used by students to predict the color, smell, and taste of chemical compounds based on their microscopic structure and composition?

Our focus on the prediction of sensory properties, such as color, smell, and taste, was intentional. These types of properties of chemical compounds are not traditionally discussed in introductory chemistry courses, but one should expect that students who truly recognize the emergent nature of chemical properties will not base predictions about sensory properties on an additive framework. Our goal was to minimize the influence of specific domain knowledge or familiarity with the subject on students’ predictions to more clearly assess intuitive reasoning. Given students’ daily experiences with the color, smell, and taste of different substances, sensory properties seemed ideal to explore the influence of commonsense reasoning on students’ decisions.

**Instruments and Data Collection**

We followed a mixed method design in which quantitative and qualitative research instruments were used (Greene, Caracelli, & Graham, 1989). The data collection was completed in three main phases: (a) sensory properties questionnaire, (b) interviews, and (c) supplemental studies. Details for each of these phases are presented in the following paragraphs. (因篇幅有限，與(c) supplemental studies 相關的實驗設計、研究結果與討論以下全部省略)

a. A sequence of short-response questions was designed to explore students’ ideas about the origin and cause of the color, smell, and taste of natural entities and chemical compounds. Examples of the types of questions used during this part of the study include: Why do lemons smell the way they do? Why don’t they smell like oranges? Why do different substances have different flavors and colors? These exploratory questions were asked during the discussion sessions of the first general chemistry course (GCI) for science and engineering majors at our university (Fall 2004), and the analysis of the students’ responses guided the construction of a short multiple-choice questionnaire that was tested with the same group of students. The results of this test were used to build a revised version of the questionnaire that then served as the main data collection instrument for the present study.

Our multiple-choice questionnaire (sensory properties questionnaire) included 12 questions that asked students to predict the color, smell, and taste of the chemical compounds resulting from reactions between two substances depicted using
particulate representations.

b. To gain qualitative insight into the students' reasoning, short semistructured interviews lasting between 15 and 25 minutes were conducted with student volunteers from general chemistry courses at our university (Fall 2005). During the interviews, participants were presented with each of the 12 questions from our sensory properties questionnaire (displayed on a computer screen), told to select an answer, and then asked to provide a verbal explanation for their choice.

Most of the student participants were enrolled in the first semester of a general chemistry course for science and engineering majors (GCI). This course covers topics such as atomic and molecular structure, states of matter, and chemical reactions (stoichiometry and thermochemistry). The main questionnaire was applied in three different sections of the course, during a class session in the fourth quarter of the academic semester. By then, the central concepts related to properties of chemical compounds and reactions had already been introduced and discussed. A total of 456 individual questionnaires were collected, although not all of the students answered every question.

The interviews involved 10 student volunteers (eight females and two males) from the GCI classes, where the questionnaire was administered, plus eight additional students (five females and three males) from the second course in the general chemistry sequence (GCII).

RESULTS
Equal Ratio; Equal Size

Question 1 in Table 1 summarizes GCI students' predictions about the color of a chemical compound resulting from a 1:1 combination of monoatomic substances with two different

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tbody>
<tr>
<td>Frequency of Responses for the Different Options Associated With Questions About the Color of the Chemical Product of the Reaction Between Two Substances (Sensory Properties Questionnaire)</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
</tbody>
</table>
colors: blue and yellow. Most of the students in the sample (90.4%, N = 447) predicted that the new chemical compound would have a green color, and only 7.61% of the participants indicated that the new substance would likely have a “different” color. Results from the interviews indicated that students who selected option “d” (green color; 60% of GCI and 50% of GCII interviewees) based their predictions on their experiences mixing colors. Many of these students referred to the chemical product as the result of “mixing” two substances and paid attention to the number of atoms of each type of substance to weigh the influence of each color (additive thinking). The following excerpt from a GCI student interview illustrates this type of reasoning:

I would choose c) [pause] because there is the same amount of particles of the blue color as of the yellow color, and there are both bonding together with one blue and one yellow so, you know is kind of equal, so both colors are balanced and when blue and yellow are mixed it creates green. (GCI6)

Students who selected option “d” during the interview (other or a different color; 40% of GCI and 50% of GCII interviewees) gave explanations that in many cases indicated recognition of either the emergence of different properties in the formation of a chemical product or the impossibility of predicting the outcome of the chemical reaction based on the information provided. The following excerpts illustrate the reasoning of participants who based their responses on an emergent framework:

If they weren’t chemically bonded then I would just say it’s a mixture of blue and yellow, which would be green, but since they are chemically bonded I think it’s plausible to say they have an entirely different color. So, I’ll select d. (GCII1)

...what I am thinking is that I wouldn’t opt for any of those options because I feel like there is no way for me to know what color that interaction is going to produce. I mean, I’m tempted to say the product has a different color because it seems intuitive that if you mix the two you are going to get something different, but I don’t know that. I don’t know what wavelengths this compound is going to reflect as compared to these two individuals. (GCII7)

However, not all of the students who chose option “d” exhibited this level of expert reasoning. Some of them based their explanations on personal ideas about the relative strength or dominance of one type of color over the other. Consider, for example, the following explanation by interviewee GCII:
I know that some colors will overpower each other and some will blend, it is all kind of relative on their chemical compounds and how they react to form other molecules, but [pause] I don’t know [pause] I have to say: a different color, just because blue may be really dominant and yellow may just blend into that. I don’t think it would be green [pause] it’s possible but I don’t think it would go that way. (GCI1)

These types of responses based on personal experience with common materials, such as paints, cooking products, and perfumes, were more commonly present in students’ explanations of the predicted taste or smell of the product of a chemical reaction. For example, of the four GCI interviewees (40%) that predicted that the smell or taste of the chemical product in the 1:1 reactions between particles of equal sizes would be “different” than that of the reactants or their additive combination (option “d” in questions I in Table 2), three of them built their justifications based on personal beliefs about the strength or power of one type of smell or taste over the other, or on personal cooking or tasting experiences. Only one of the GCI interviewees gave consistent explanations based on scientific understanding of chemical properties. Commonsense reasoning based on the idea of “dominance” was also frequent in students who predicted that the product would have a smell or taste similar to that of one of the reactants (such as salty or minty, for example). The following interview excerpts illustrate this type of thinking:

I think it would be salty [pause] 'cause salt would react with more of the taste buds. [pause] I don’t know, it would overpower everything. (GCI3)

Well, rose once again is still a light smell no matter how much you have of it. Mint is very strong and it’s supposed to kill off other smells too. I would personally think the mint should override the rose; of course you should able to smell the rose but not as strongly as if it was just the pure rose. I would probably smell more of the mint. (GCI4)

**TABLE 2**

Frequency of Responses for the Different Options Associated With Questions About the Smell and Taste of the Chemical Product (Sensory Properties Questionnaire) [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

<table>
<thead>
<tr>
<th>Option</th>
<th>Mint</th>
<th>Rose</th>
<th>Mint-Rose</th>
<th>Other</th>
<th>No smell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smell?</td>
<td>5.97%</td>
<td>1.98%</td>
<td>69.0%</td>
<td>20.6%</td>
<td>0.442%</td>
</tr>
</tbody>
</table>
The existence of personal ideas about dominant smells and flavors may explain why a larger number of students selected option “d” (other or a different smell or taste) in answering questions I in Table 2 (20.6% for smell, N = 452; 23.7% for taste, N = 447), compared to the number who chose the equivalent option in the prediction of the color of the chemical product (7.61% in row I in Table 1, N = 447). Our interview results suggest that it is likely that a significant proportion of these students did not base their response on the application of an emergent framework in the prediction of the properties of the chemical product, but rather were using an additive framework that includes commonsense ideas about some properties being more “dominant” than others. This assumption is further reinforced by the frequent inconsistencies detected in the students’ responses within this set of questionnaires. During the interviews, the few students who demonstrated a solid understanding of the emergent nature of chemical properties (one of ten GCI interviewees and four of eight GCII interviewees) were very consistent in their predictions of the likely outcome of each chemical reaction. On the contrary, students who based their responses on additive reasoning combined with personal ideas about “dominance” of one property over another were rather inconsistent in their predictions. This suggests that consistency of responses within a single questionnaire may serve as an indicator of the type of reasoning that GCI students in the larger sample may have followed.

Different Ratio; Equal Size

The students’ tendency to apply an additive heuristic in the prediction of the color of the product of a chemical reaction seems to be confirmed by the answers to the other three questions in the color set. Question II in Table 1 depicts the results for the prediction of the color of a product resulting from the 4:1 combination of monotonic substances that are blue and yellow, respectively. In this case, a large proportion of the students (79.6%, N = 455) indicated that the product would have a bluish color (option “a”). This type of answer may be expected from an intuitive thinker who applies an additive rule in which the properties of the product result from the weighted average of the properties of its components. All of the interviewed students who selected this option (90% of GCI and 37.5% of GCII interviewees) used the larger number of blue atoms than yellow atoms as the main rationale for their predictions. Some of these students also referred to the distribution of atoms in the molecule to justify their answer:

I would say the color is blue because there are more bluish dots than yellow dots, and all the bluish dots are kind of surrounding the yellow, so the yellow won’t be able to come out.

(GC16)

IMPLICATIONS

The analysis of all questionnaires
indicates that less than 3% of the students who participated in this study uniformly and systematically predicted that the properties of a chemical product may be expected to differ from those of the reactants. Even in these cases, it was common to find at least one answer that showed signs of the use of an additive framework as the basis for the prediction. These results are rather surprising if we consider that most of the participants in this study were college students who had almost completed the first semester of a general chemistry course for science and engineering majors.

The analysis of the interview transcripts revealed that students who frequently selected the “additive” options (80% of GC1 and 40% of GCII interviewees) seemed to conceive of chemical compounds as mixtures of substances that preserve some of their original properties in the final product. Thus, these students had not developed an emergent view of chemical properties. Results from the interviews also suggest that variations in the students’ predictions about smell and taste compared to those of color may be largely attributed to the influence of personal ideas about the relative strength of scents and flavors or a person’s ability to sense them, rather than to the meaningful understanding of the emergent nature of these properties. Many students seem to consistently use an additive framework to make predictions about the properties of the product, but they also apply some sort of “dominance principle” in which those flavors or odors perceived as more dominant determine the actual outcome.

Our study illustrates the pervasive nature of commonsense reasoning in chemistry students and reveals serious deficiencies in their preparation. Intuitive thinking seems to lead many students to conceive of physical and chemical properties as additive rather than emergent properties, similar to the way they tend to misclassify emergent processes as direct processes (Chi, 2005). As reported by previous authors (Ben-Zvi et al., 1987a; Boo & Watson, 2001), our work indicates that a large proportion of chemistry students conceive chemical reactions as additive rather than interactive, and that traditional courses in the discipline have little effect on these ideas.

Helping students recognize the existence of emergent properties in chemical systems is crucial if we want them to develop meaningful understandings of a variety of topics, from the atomic and molecular properties of individual particles to the behavior of many-particle systems (states of matter). To support learning and teaching in this area, more research is needed to better understand how students’ reasoning about physical and chemical properties progress from reliance on additive to emergent frameworks. The present work is a first step in that direction.
For many years, chemical educators have argued that commonsense reasoning plays a minor role in the development of students' misconceptions in chemistry given the abstract nature of many chemistry concepts (atoms, molecules, acids, oxidizing agents) (Taber, 2001). However, our research indicates that students' empirical assumptions about the natural world and their simplistic reasoning heuristics seem to undergird many of their alternative conceptions (Talanquer, 2006). In particular, this study reveals that the concept of "emergence" is not trivial and that intuitive thinking may limit students' ability to transfer their knowledge to different contexts. If students hold essentialist views about certain properties, such as color or smell, they may think that these properties are intrinsic to atoms or elements and thus should be present in their molecules or compounds. Changing these ideas will require more than mere explanations or exposure to chemical reactions in which the properties of the products differ from those of the reactants. The task will require the intentional design of learning opportunities for students to recognize and differentiate additive and emergent properties in a variety of contexts and to critically reflect on the relationship between molecular structure and observable properties.