Educational research

Contrasting the expectations for student understanding of chemistry with levels achieved: a brief case-study of student nurses

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Abstract: This case study examines the understanding of a small sample of nursing students in some aspects of general chemistry. In the United States most nursing programs require college-level nursing courses, with expectations that students will master basics of first-year general chemistry. Anxiety to achieve passing grades in such courses is high for nurses, and the courses are sometimes seen as a gatekeeper for who has access to the profession. This study examines understanding achieved for a small sample of nursing students regarding aspects of matter — basic ideas regarding understanding of matter composition, structure, amounts and properties. Our intention is to highlight the contrast between what chemistry knowledge is expected of nurses and what level they actually achieve, and what this may mean for their future professional performance. Findings include that the nursing students in the sample had limited understanding of the university-level chemistry they were being asked to master, and exhibited less comprehension and more pervasive misconceptions than comparison groups, including first term high school students, in our sample. [*Chem. Educ. Res. Pract.*, 2006, **7** (3), 170-184]

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Introduction

In a discipline such as chemistry, it is sometimes asked whether students really need to learn the material to which they are being exposed. Some argue that perhaps the exposure itself, as an 'exercise of the mind' or even as 'armchair touring' of a new intellectual domain, is sufficient when studying sciences such as chemistry, unless the student has plans to become a scientist, doctor or engineer.

One argument in favor of improved levels of scientific literacy often is that demands of so many of today's career paths require at least some and often much understanding of basic science. Here we look at a brief case study of nursing students studying chemistry, and the demands placed on their scientific knowledge by their field. Data in this paper include assessments on a group of about seventy nursing students at the completion of their required general chemistry training for satisfaction of certification requirements in a degree program leading to the RN, (registered nurse) license granted to professional nurses in the U.S., along with a bachelor's degree. The nursing students were among several different levels of chemistry students assessed in the development of assessment instruments for an NSF-funded project called ChemQuery (Scalise, 2004) and were selected only as a 'convenience sample', students readily available through their instructor and willing to participate to gain some extra credit in their course. This brief case study is not intended as a broad analysis of the chemistry training of nursing students, but is illustrative of the dilemma of the degree to which careers today can place high demands on science knowledge for the broader population.

While we expected to see previously well-documented misconceptions (see section on Conceptual Change) from the high school students in our sample, we were surprised to see an even greater level of misconceptions (a higher percentage of students broadly exhibiting misconceptions) from this sample of university-level students. In assessing chemistry students with varying instruction in the discipline, our hypothesis had been that, for the sample groups with which we worked, we would find the least understanding at pretest in high school students (with no former chemistry-specific coursework), followed by high school students at post-test after instruction, first-year university students in chemistry in non-science major tracks such as nurses, first-year university students in chemistry in science/engineering major tracks, second year chemistry students (students who stay with chemistry through second year tend to be science/engineering majors) and science students at the completion of their second year studies in chemistry. Our studies found this trend, with the notable exception of first-year university students in the biomedical, nursing pathways, for whom post-test scores were lower than the high school student post-test scores and close to high school students at pretest (novice to any formal instruction), showing major embedded misconceptions regarding basic characteristics of matter and of reactivity.

Overview of some aspects of nursing, as they relate to the need to know chemistry

Chemistry often is viewed as an essential foundation for the health professions, not just for doctors but for nurses, paramedics, technicians, respiratory therapists, waste disposal professionals and many others who handle the wide and still growing range of chemicals in modern healthcare. That this is a large group of people is undeniable. In the United States alone, there are over 2 million jobs for registered nurses, and "*nursing is the largest of all the health care occupations and the second largest of all professions…. (Teaching is the largest profession in the U.S. today.)*" (Lanzer, 2000). In addition, the health care sector is growing: it is "*one of the top 10 occupations projected to have the largest number of new jobs through 2008.*"

Nurses today can be called upon to act with a great deal of autonomy in monitoring and responding to complex technical situations. Cytotoxic drugs are common and considerations such as what the drug is, dosage and concentration are important to understand. When treated patients return to their units, general-care nurses are often responsible for chemical safety considerations and toxic waste disposal concerning byproducts of the dangerous drugs. Furthermore, as nurses train for their disciplines and specialties, coursework in physiology, microbiology and biochemistry classes often requires a basic understanding of chemistry.

Thus, accreditation groups for nursing education in the U.S. tend to require significant education in chemistry. While licensing for nurses in the U.S. is the responsibility of each state, the U.S. Department of Labor Bureau of Labor Statistics (U.S. Department of Labor, 2006) reports that as a general trend across the U.S., university level chemistry courses are required for nurse training programs. For the nursing students in this sample, the chemistry course requirement for completion of the nursing program is a one-year sequence, consisting of one 10-week term of general chemistry and then a term each of more advanced coursework in organic and biochemistry. Students in this study were assessed at the end of general chemistry, which consisted of 10 weeks of instruction at six contact hours per week, a total of 60 contact hours. Students are also expected to spend an additional eight hours per week on course assignments in general chemistry during this time, for a total of 140 hours spent over the term engaging with the concepts and ideas of general chemistry. This had been believed to be sufficient to build a base of understanding for more advanced work in organic and biochemistry, and to support subsequent learning in physiology and microbiology courses.

Additionally, while chemistry is perceived by the profession as an important required course for many individuals in the healthcare sector, it has been reported that ‘chemistry anxiety’ can run high for students enrolled in chemistry courses (House, 1995; Eddy, 2000). For the purposes of this paper, we include here a few nurse-specific ‘chemistry anxiety’ comments, citing from one thread of discussion on balancing chemical equations by student nurses in an Internet nursing discussion forum (allnurses.com, 2004). The discussion began with a question from a student nurse about balancing a reaction for a class being taken, and launched a torrent of discussion on the fears and anxieties associated with study of chemistry. Student nurses commented on homework solutions that they had been told were correct but they could not ‘see’ why the solutions were correct. Others talked about the difficulties in recognizing what their chemistry textbooks were talking about, and described how chemistry was an aggravating class because they felt they had limited ability to make sense of the coursework. One student nurse commented: “*I’m taking chem. starting in July and y’all are scarring the H.E.L.L out of me....*”

Conceptual change in chemistry: a brief review of some of the literature

Many researchers studying student conceptions and misconceptions in chemistry have focused on student understanding in two areas: the structure of matter and reactivity. Here we will share a few of the classic studies and seminal papers in chemistry misconception research. Regarding matter, many students even after instruction of from weeks to months retain a ‘concrete, continuous’ view of atoms and molecules, in which each particle retains the macroscopic properties of a small piece of its parent substance (Ben-Zvi, Eylon, & Silberstein, 1986). Subjects often believe water molecules, for instance, contain components other than oxygen and hydrogen, such as water, air, chlorine, minerals and ‘impurities’, or may have shapes in different phases, e.g. water molecules frozen into ice cubes are square (Griffiths & Preston, 1992). Individual molecules can be ‘hot’ or ‘cold’, and belief in atoms and molecules as alive is common (de Vos & Verdonk, 1985).

Regarding reactivity, gaseous products or reactants are often ignored (Hesse & Anderson, 1992), reflecting the view that substances that float in air have no mass and thus are not substances that need to be conserved (Samarapungavan & Robinson, 2001). Even after university level instruction, most students do not understand chemical reactions as reorganization of atoms, with breaking and re-formation of bonds. For instance in one study, only 6% of secondary and 14% of university chemistry students could, after instruction, describe chemical reactions as the breaking and re-forming of bonds (Ahtee & Varjola, 1998). Students often ignore laws and theories of reactivity, and transform equation writing into a mathematical game of getting symbols to add up (Yarroch, 1985).

Driver and other researchers have emphasized the interplay among the various factors of personal experience, language and socialization in the process of learning science in classrooms and argue that it is important to appreciate that scientific knowledge is both symbolic in nature and also socially negotiated (Driver and Scanlon, 1989; Driver, et al., 1994). By socially negotiated, these researchers mean that scientific entities and ideas are unlikely to be discovered by individual students through their own empirical enquiry, so learning science involves being initiated into the ideas and practices of the scientific community.

Hesse and Anderson (1992) have argued that it takes time to build sufficient understanding to be able to combine scientific models with prior knowledge and develop working understanding on which knowledge of chemistry can build. They argue that while the rules for writing and balancing chemical equations are fairly simple, the equations that result are meaningful only when they are embedded in a complex 'conceptual ecology' — an array of facts, theories, and beliefs about the nature of matter and the functions of explanation that chemists have developed over time, and that is part of the discourse language in chemistry.

In this study of student nurses, we see the research on the strength of misconceptions and on the length of time involved in developing a working knowledge of chemistry as being in conflict with the practice of training nurses, where they are expected to develop substantial understanding of general chemistry in just 10 weeks of study and with the students' experience of anxiety when confronted with material beyond their mastery.

Theoretical framework

We are currently engaged in developing a formative assessment system for classroom-based use in high school and university-level general chemistry, using the BEAR (Berkeley Evaluation & Assessment Research) Assessment System (Wilson and Sloane, 2000). The goal of the project is to develop one approach, of perhaps many possible useful approaches, to an assessment system for general chemistry that can map student progress in their comprehension and use of overarching ideas. The assessment system uses a framework called the *Perspectives of Chemists* (Claesgens, et al., 2002) of some of the key ideas in the discipline and criterion-referenced analysis with item response models (IRT) to map student progress.

To interpret the findings in the data section of this paper, it is important to have an understanding of the levels of the Perspectives framework, see Figure 1. On a 15-point scale, with 15 points as the highest score:

- Students score 1-3 for answers that exhibit a *Notions* view on assessment tasks. Notions answers involve the use of sound reasoning skills such as pattern matching, logic, real-world experience and mathematical skills *but no normative science models* to respond to questions and tasks.
- Students score 4-6 for answers that exhibit a *Recognition* view on assessment tasks. Recognition answers involve the use of a very simplistic single aspect of a normative science model as a conceptual and problem-solving strategy. Across questions, students at this level draw on some single aspect of an appropriate science model to reason, and show some emerging strategic competence in selecting an appropriate model. However, it is very rare for students with this strategy to extend explanations to consider more than one aspect of the model, *though in moving from one question to another they often show knowledge of multiple aspects.*

Figure 1. Perspectives of Chemists Framework.

ChemQuery Assessment System: Perspectives of Chemists on Matter

Generation 13-15	Bonding models are used as a foundation for the generation of new knowledge (e.g., about living systems, the environment, and materials).	Students are becoming experts as they gain proficiency in generating new understanding of complex systems through the development of new instruments and new experiments.	a) Composition: What is the composition of complex systems? (e.g., cells, composites, computer microchips) b) Structure: What gives rise to the structure of complex systems? (e.g., skin, bones, plastics, fabrics, paints, food,) c) Properties: What is the nature of the interactions in complex systems that accounts for their properties? (e.g., between drug molecules and receptor sites, in ecosytems, between device components) d) Quantities: How can we determine the composition of complex systems? (e.g., biomolecules, nanocomposites)
Construction 10-12	The composition, structure, and properties of matter are explained by varying strengths of interactions between particles (electrons, nuclei, atoms, ions, molecules) and by the motions of these particles.	Students are able to reason using normative models of chemistry, and use these models to explain and analyze the phase, composition, and properties of matter. They are using accurate and appropriate chemistry models in their explanations, and understand the assumptions used to construct the models.	a) Composition: How can we account for composition? b) Structure: How can we account for 3-D structure? (e.g., crystal structure, formation of drops,) c) Properties: How can we account for variations in the properties of matter? (e.g., boiling point, viscosity, solubility, hardness, pH, etc.) d) Amount: What assumptions do we make when we measure the amount of matter? (e.g., non-ideal gas law, average mass)
Formulation 7-9	The composition, structure, and properties, of matter are related to how electrons are distributed among atoms.	Students are developing a more coherent understanding that matter is made of particles and the arrangements of these particles relate to the properties of matter. Their definitions are accurate, but understanding is not fully developed so that student reasoning is limited to causal instead of explanatory mechanisms. In their interpretations of new situations students may over-generalize as they try to relate multiple ideas and construct formulas.	a) Composition: Why is the periodic table a roadmap for chemists? (Why is it a 'periodic' table?) How can we think about the arrangements of electrons in atoms? (e.g., shells, orbitals) How do the numbers of valence electrons relate to composition? (e.g., transfer/share) b) Structure: How can simple ideas about connections between atoms (bonds) and motions of atoms be used to explain the 3-D structure of matter? (e.g., diamond is rigid, water flows, air is invisible) c) Properties: How can matter be classified according to the types of bonds? (e.g., ionic solids dissolve in water, covalent solids are hard, molecules tend to exist as liquids and gases) d) Amount: How can one quantity of matter be related to another? (e.g., mass/mole/number, ideal gas law, Beer's law)
Recognition 4-6	Matter is categorized and described by various types of subatomic particles, atoms, and molecules.	Students begin to explore the language and specific symbols used by chemists to describe matter. They relate numbers of electrons, protons, and neutrons to elements and mass, and the arrangements and motions of atoms to composition and phase. The ways of thinking about and classifying matter are limited to relating one idea to another at a simplistic level of understanding.	a) Composition: How is the periodic table used to understand atoms and elements? How can elements, compounds, and mixtures be classified by the letters and symbols used by chemists? (e.g., $CuCl_2$ (s) is a blue solid, $CuCl_2$ (aq) is a clear, blue solution) b) Structure: How do the arrangements and motions of atoms differ in solids, liquids, and gases? c) Properties: How can the periodic table be used to predict properties? d) Amount: How do chemists keep track of quantities of particles? (e.g., number, mass, volume, pressure, mole)
Notions 1-3	Matter has mass and takes up space.	Students articulate their ideas about matter, and use prior experiences, observations, logical reasoning, and knowledge to provide evidence for their ideas.	a) Composition: How is matter distinct from energy, thoughts, and feelings? b) Structure: How do solids, liquids, and gases differ from one another? c) Properties: How can you use properties to classify matter? d) Amount: How can you measure the amount of matter?
Level of Success	**Big Ideas**	**Descriptions of Level**	**Item Exemplars**

- Students score 7-9 for answers that exhibit a *Formulation* view on assessment tasks. Formulation answers involve the highest strategy observed in the initial informant group of mainly high school students but also some introductory chemistry college students. Formulation involves use of and relating multiple aspects of normative science model, see Figure 1 framework description for more details of these models. Here students begin to bring together the multiple aspects of knowledge revealed but not often used together at Recognition. However, student understanding of the broader context of chemistry is still weak, so student answers often over generalize, or relate principles to situations outside the correct scope.
- Students score 10-12 for answers that exhibit a *Construction* view on assessment tasks. Construction answers were not observed among any students at the high school level but were identified sometimes at the general chemistry level and often among the students completing organic chemistry at UC Berkeley. This higher level reasoning strategy involved relating not only multiple aspects of a model, but more fully considering all aspects, for a fuller ‘model view’ response, see Figure 1 for details of the models involved regarding Matter.
- Note that the Perspectives framework also includes a 13-15 *Generation* category, not involved in this study.

Methods

Data source and assessment instruments

A total of 638 students participated in the Perspective of Chemists study, of which sixty-seven were nursing students who are the subject of the case study in this paper. The additional students are described in the results section of this paper as comparison groups, so the full student sample will be described here:

- There were 399 students at the university level in UC Berkeley's Chemistry 3B course. These students, usually in medical or biological science pathways, were on the verge of completing their second semester course in organic chemistry when they participated in Smart Homework. Most had a prior year of general chemistry at the university level and a prior year of high school chemistry, although some combined the high school and university first year by completing advanced placement chemistry, or in other words a university level chemistry course while still in high school, or by taking only one semester of university general chemistry in addition to high school chemistry.
- A further 117 students had just satisfied the requirement for completion of first-year general chemistry at UC Berkeley and had enrolled in the first organic chemistry course in the bioscience pathway. Most of these students, usually in a medical or biological science pathway major, had a year of general chemistry at the university level and a prior year of high school chemistry, although some again combined the high school and university first year.
- Sixty-seven students were completing their general chemistry studies at another four-year public university in California, in the medical pathway, most training to become nurses. This university focuses on expert instruction in small classes and offers more than 100 fields of study. It was recently selected as a 2005 Best College in the U.S. Western Region by *The Princeton Review*, which rates college programs for undergraduates. The campus has a

history of excellence in teaching and relatively high faculty-student ratios for California (1:22).

- Fifty-five students were secondary students in high school chemistry at a Catholic high school in the San Francisco Bay Area.

The nursing students in this case study were enrolled in an undergraduate program leading to the Bachelor of Science degree with a major in Nursing, ‘designed to prepare a nurse generalist’ who could work as a professional nurse or pursue graduate training in nursing. The chemistry course requirement for the program is a one-year sequence ‘for students prepared for careers in health-related sciences including nursing.’ The year consists of 10 weeks of study in general chemistry which is intended as foundation for a subsequent 10 weeks of study in organic chemistry and 10 weeks in biochemistry.

Students in the nursing sample were measured just prior to the final examination for the first quarter course in general chemistry, which explored atomic and molecular structure and related to topics mostly in the area of Matter as described by the Perspectives framework, see Figure 1. The assessment tasks were selected by a chemist working with the nursing course instructor to address specifically the material these students had been taught during the quarter, and not to include other material available in the assessment bank that had not yet been taught to these students.

BEAR Assessment System tasks are typically ‘embedded’ assessments, or in other words assessments placed within learning materials used in classrooms or for classroom-based instruction. For this case study, the assessments were part of the BEAR CAT Smart Homework implementation. BEAR CAT — Berkeley Evaluation and Assessment Research Computer-Adaptive Tools (Scalise and Scalise, 2004) — is a computer adaptive version of the BEAR criterion-referenced assessment approach described previously. BEAR CAT Smart Homework consists of homework sets designed to adapt to the individual needs of different students in near real-time, by electronically adjusting questions and feedback to the measured levels of the Perspectives performance framework.

A team of chemistry content experts at UC Berkeley designed the adaptive Smart Homework content. The multimedia package was built and delivered through the Distributed Learning Workshop's Learning Conductor software (http://www.dlworkshop.net/), modified to make the BEAR CAT adaptivity possible. We describe the environment afforded by the modified tools as an ‘Autonomous Learning Environment’, potentially capable of supporting not only adaptive homework described here, but also many other kinds of guided, independent (autonomous) learning activities that employ adaptivity (Scalise and Wilson, 2005).

Question and task formats in the Smart Homework sets varied. Some were multiple choice, others open-ended and requiring composed or calculated answers. Both right/wrong (dichotomous) and partial credit (polytomous) scoring schemes were used. The partial credit score levels were assigned based on the Perspectives of Chemists framework previously described.

We list here some technical information that is helpful to understand the evidence when computer adaptive instruments are used for assessment. Note that computer adaptivity, and thus the more complicated measurement approaches described below, were used because we wanted to assess students at a wide range of proficiency with the homework sets, from novice to any chemistry instruction through three years of instruction. Standard tests that gave the same questions to everyone would not readily assess this range in a single instrument. Computer adaptive instruments overlap enough items between students to put all the students on a common scale but are also able to extend up for students showing high proficiency and down for students showing low proficiency.

The primary item design in BEAR CAT is the ‘testlet’, or item bundle, which in this case consisted of an initial prompt, or question, followed by ‘probes’ or subsequent tasks of varying difficulty depending on how the student performed on the previous questions.

The BEAR CAT Smart Homework sets for the 521-person study consisted of a bank of about 15 testlets, consisting of a total of about 100 items. The ACER ConQuest Generalized Item Response Modelling Software (Wu et al., 1998) was used to calibrate the items and generate parameters under two item response models: partial credit and iota models. The details of the partial credit and iota model are discussed in more detail in other papers (Scalise and Scalise, 2004; Scalise and Wilson, 2005). The partial credit model allows students to be given partial credit on an assessment task, according to the scoring in the Perspectives framework, and then the difficulty of achieving each level of partial credit is estimated and student ability estimates and standard errors around the estimates can be assigned by score level. The iota model, which is a multi-facet bundle model, takes this approach to partial credit scoring one step farther for computer adaptive contexts, where considerations of the various student paths through multiple possible item sets and issues of statistical dependency may arise (Scalise and Wilson, 2005). In computer adaptive testing with questions and follow-up probes students may take different paths through the questions and probes, but ultimately arrive at providing the same answer, and thus receive the same score via different paths of probes and answers. The iota model estimates the difficulty of achieving each path, so that paths to the same score can be compared for whether, based on empirical data, they are equivalently difficult, as predicted. This tests whether path independence is a reasonable assumption for a particular computer adaptive assessment instrument based on testlets.

EAP/PV reliability for the 15-testlet BEAR CAT instrument was 0.82, which shows good reliability and indicates a slightly higher than 0.9 correlation with the expected true score, if the assessment were taken many times. Standard errors for the BEAR CAT instruments were small so that virtually no students would be expected to move from Notions to Recognition or Recognition to Formulation if they were retested or were given other items from the bank, unless the student had happened to measure at a point very near to the boundary between the two levels. Note that a study was conducted comparing measurement via the BEAR CAT Smart Homework instruments with a constructed-response instrument and a multiple-choice control comparison instrument from Kaplan AP Chem preparatory materials (Dumas et al., 2003). Student placement, fit and distribution on the three instruments was found to be quite comparable, and the instruments measured similarly in the validity study (Scalise and Wilson, 2005).

Results

Comparison results

The comparison groups investigated in this study were high school students in first-year introductory chemistry, nursing students at a public university completing the first quarter of university-level general chemistry for their pathway, UC Berkeley students soon after completion of their first-year general chemistry requirement as they began second-year organic chemistry for bioscience pathways, and UC Berkeley students at completion of second-year organic chemistry for bioscience pathways. Generally, the performance trend was expected to be lowest with high school students, and rising for students with increasingly more exposure to university-level chemistry.

While mean scores generally reflected this trend, the exception was the nursing student cohort, which had a somewhat lower mean score after completion of university-level general chemistry than the high school students in our sample. The mean high school scores for the 2003 high school 'Living by Chemistry' student cohort who used the BEAR CAT instrument showed about 90% of students measuring in Recognition and 10% in Notions. It should be noted that these students were at a generally high performing school, drawing from a relatively high socio-economic population, so unsurprisingly, performed academically better than average high school students. More typically, from the larger studies of high school students in our trials not reported here, high school students have been found to score about half in Notions and half in Recognition at the point in the curriculum at which these high school students were measured.

By comparison, the nursing students scored lower than these high school students, and somewhat lower than average high school students, based on past trials, with 75% of the nursing students measuring in Notions at the end of general chemistry and only 25% measuring in Recognition. Additional support for the placement of these students mostly in Notions comes from qualitative analysis of their responses to open-ended items, where the majority of the responses also fell into the Notions level (see Table 1 for an example of answers on one question and Table 2 for summary statistics over a set of items).

Table 1. Facets of reasoning used in student responses regarding why N_2H_6 does not exist, a valence electron question.

If NH_3 exists, why doesn't N_2H_6?	**N**	**%**	**Level**
I don't know, 'no idea', or non-response	13	21.7	0
N_2H_6 can be made, question is wrong	1	1.7	1
N_2H_6 name is wrong (no explanation for why not)	1	1.7	1
NH_3 and N_2H_6 have different names	1	1.7	1
gases can't be put in a container	2	3.3	2
nitrogen and hydrogen can't be mixed	2	3.3	2
the container will be too full with more gas	2	3.3	2
NH_3 cannot be broken apart	6	10.0	2
NH_3 can't be 'doubled' to make N_2H_6 (no explanation)	1	1.7	2
not enough nitrogen available to make N_2H_6	5	8.3	2
N and H both have the same charge (+ or –)	2	3.3	3
Conditions aren't right (acidity or non-aq.)	2	3.3	3
Nitrogen only forms triple bonds	1	1.7	3
Conservation of Mass—not all particles conserved[1]	10	16.7	3
N ion has a charge of 3, H ion has a charge of 1	2	3.3	3
Charges won't balance	1	1.7	4
Valence elec., octet rule or Lewis dot described but inaccuracies	5	8.3	4
Valence elec., octet rule or Lewis dot fairly correctly	3	5.0	5

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[1] These answers appear to be based on confusing this question with a prior question in which carbon was included as one of the reactants.

UC Berkeley students in the bioscience pathway at the completion of first-year general chemistry measured about 15% in Notions, about 45% in Recognition, 35% in Formulation and slightly less than 5% in Construction, showing the broadest spread of levels of any of the groups.

By the end of second-year organic chemistry, the sampled students in this pathway measured about 20% in Recognitions, 75% in Formulation and slightly less than 5% in Construction. Generally, the spread of students over Perspectives levels was much greater at the beginning of organic chemistry than at the end, where by the time they completed organic chemistry most students had progressed to Formulation and none remained in Notions. This may be a combined effect of learning over instructional time and the attrition of lower performing students.

Facets results

As discussed in the analysis section, the performance of the nursing students was heavily clustered in the Notions level, where responses revealed for the most part sound reasoning with real-world knowledge, pattern matching and logic, but no use or attempted use of actual domain knowledge in chemistry by most of the students, following the 10 weeks of instruction in this course. About 75% of the students measured in Notions. The remaining 25% had achieved the transition to Recognition, where they were beginning to use chemical knowledge in simple definitional ways with some but limited accuracy, which is probably well in accord with the intentions of the course. To frame this in terms of what nurses would actually need to know on the job, a reasonable understanding of concentration of solutions, for instance, would seem to be a key aspect of knowledge for proper monitoring of administration and dosage of medications. This, however, would fall into the next level, or Formulation level of the framework, two levels above Notions where most of the nursing students measured at the completion of their study of general chemistry. A beginning conceptual understanding of concentration might be expected to start to develop in the higher levels of Recognition, while only about 25% of the nursing students had achieved even the lower levels of Recognition by the end of their general chemistry course.

To give an example of actual student answers and how they may relate to notions and misconceptions about matter, the qualitative data in Table 1 considers the facets of student understanding on one assessment task, taken by most of the nursing students through the computer-adaptive instrument, in which students were asked to explain why NH_3 exists but not N_2H_6. This question taps fairly typical general chemistry content regarding bonding rules, and what atoms can be expected to combine to form what molecules. A possible correct answer at a Recognition level, a low level but definitionally correct answer could, for instance, involve NH_3 having the correct number of valence electrons to satisfy the octet rule, while N_2H_6 does not. Other ways of expressing this could include discussing noble gas configurations or showing Lewis Dot diagrams. Higher level answers on this question could, of course, involve more expert answers and explanations.

Table 1 identifies the facets of reasoning used in student responses, and shows percentages across facets and scores assigned according to the Perspectives framework. To summarize the data, after one quarter of general chemistry only three of the sixty students who engaged in the assessment task were able to answer this question correctly at the Recognition level, with five others on the right track in thinking about valence electrons and bonding but somewhat misinterpreting concepts.

Table 2. % of respondents scoring at each level, for a set of items taken by most of the nursing students.

Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	21.7	20.6	16.7	19.7	15	0	0
1	5.1	3.2	1.7	0	1.7	21.1	21.4
2	29.9	7.9	1.7	25.8	20	7	10.7
3	28.3	19	18.3	31.8	36.7	22.8	0
4	10	36.5	46.7	16.7	25	49.1	67.9
5	5	12.7	15	6.1	1.7	0	0
Mean level	2.15	2.86	3.22	2.44	2.6	3	3.14

Table 2 shows a summary of similar score data across general chemistry items that most students took in the BEAR CAT testlets. As shown in the bottom row of Table 2, the mean Perspective level scores across items ranged from 2.15 to 3.22. (We leave the decimal showing in the mean rather than rounding down to the actual 2-level score awarded or up to the 3-level score to give the reader a better indication of where the mean fell). With scores 0-3 falling in Notions and scores 4-6 in Recognition, this again shows that across numerous general chemistry items, the student nurse sample strongly tended to respond with Notions prechemistry ideas, or that is with ideas that did not reflect any correct use of normative chemistry models, even at a very basic definitional level.

Nursing facets as they relate to conceptual change and misconceptions

The reasoning facets data described above in the qualitative example are typical of student performance across items and relate to the previously discussed conceptual change findings in chemistry. Again we will use the NH_3 question as a typical example to get a sense of student reasoning patterns. Regarding the two major areas of evidence collection in chemistry misconceptions research – structure of matter and concepts of chemical reactivity — the 18% of students who responded with facets describing NH_3 as a molecule that cannot be broken apart or from which there would not be enough nitrogen to make N_2H_6 show misconceptions in the particulate view of matter, at the molecular level in the first example and at the systems level in the second example. The 10% of students who focused on macroscopic reasons, such as the container being too full for the reaction to occur showed, depending on aspects of their answers, misunderstanding of gas characteristics, principles of reactivity and/or conservation of mass. The 22% of students who said they had 'no idea' why N_2H_6 did not exist showed an inability to enter the problem space of considering either macroscopic or particulate explanations for the behavior, though the atomic view of matter had been the focus of their course in general chemistry.

In reference to the character of scientific knowledge as symbolic in nature, effective understanding of the symbol systems of chemistry includes making them meaningful in the context of thinking about basic models of particulate matter and chemical reactivity. Students here showed some ability to parse N as nitrogen and use other basic symbols of the periodic table, but many retained a concrete, continuous view of matter. The symbol systems themselves and how they are meaningful in applied contexts may be an important component of what nurses need to know in practice, for instance in conditions such as acidosis when nurses are need to correctly interpret the meaning of hydrogen ion concentrations and pH.

Discussion

For this small sample of nursing students, who were not intended to be a generalizable sample but only a case study, there was a large difference between what was mastered following completion of their general chemistry requirements and even the emergent beginnings of moving from a 'notions' view of chemistry and toward a basic definitional understanding of simple principles of particulate chemistry, from which knowledge of concentration, solubility, behaviors of gases and liquids, and other important considerations could be interpreted. Nursing students were studied at the end of general chemistry for several reasons, including that their subsequent studies in organic chemistry and biochemistry were intended to build on a foundation of knowledge from general chemistry. We wanted to see whether understanding at the end of general chemistry revealed a base upon which the nurses might successfully build. For most of the students, the answers revealed what might be called 'prechemistry' reasoning, or in other words reasoning that drew on logical patterning or attempted to apply real-world experience but did not use models or concepts of general chemistry.

This is not different from what has been found in other areas of introductory chemistry teaching and learning, where despite instruction in chemistry that ranged from a few months to a year or more, many students retained a concrete, continuous views of atoms and molecules. Reasoning facets of nurses regarding gases, for instance, that seem to agree with this continuous view include that gases cannot be put in containers, that during reactions in containers no more gases could be generated if gases currently were present in the container because the containers would already be full, and that the atoms of a molecule of gaseous substance cannot be recombined and rearranged in a chemical reaction.

However, while we expected to see such misconceptions from the high school students in our sample, it was a surprise to us to see an even greater level of misconceptions from this sample of university-level students, as measured by a higher percentage of students broadly exhibiting thinking at the prechemistry or Notions level across numerous items.

Of course the preparedness and abilities of the entering student population to any particular program of study are likely to affect how quickly students may master new knowledge. While we have no data to report on, for instance, student verbal and quantitative ability for the various sample groups given, UC Berkeley, as a top public research university, has a student population that tends to score considerably higher on these measures than most other four-year universities in California, so they could be expected to outpace students at other universities. However, the nursing students scored similarly at the end of general chemistry to disadvantaged high school populations we have studied in low socio-economic areas after a module of just six weeks of general chemistry instruction. This is true even where all the high school students are required to enroll in chemistry so that there is no selectivity effect in the high school population and when many of these students would not qualify for admittance to the California four-year public university from which the nurse sample was drawn. In this regard, the nursing students can be seen as better prepared than some of the comparison groups we have studied.

In any case, if courses in chemistry are mandatory because of skills supposedly needed in professional work, then it would seem that more attention must be paid to how such skills are to be mastered. This seems especially true, knowing that incoming preparedness for professional programs such as presented here may likely be an additional challenge as compared, for instance, to educating science students at top research universities. Conceptual change research does not suggest that such expectations can be met in such brief courses of study as are currently the norm. Alternatively, if such skills are not deemed necessary, then perhaps standards and the contents of courses of instruction might need to be adjusted when considering the educational needs for practice in this large field, as the course can function as a gatekeeper, generating anxiety and perceptions of limiting access to the field. This practice/research dilemma includes the fact that many students are both frustrated and/or anxious about their degree of mastery, which has been shown to be low for at least this sample, yet most who do attempt and complete the courses also go on for successful careers in these professions.

This raises several questions, including whether the degree of mastery is greater than that suggested by this study or whether students passed qualifying examinations such as the final examination without a real understanding of the subject. The validity and reliability evidence for the student measures in this study is rather strong, and qualitative inspection of student answers such as can be seen in the example question indicates lack of student understanding. Assessment research in chemistry has also shown that students can often problem-solve sufficiently in some examinations without much real understanding of the underlying concepts (Ahtee and Varjola, 1998).

That nurses who show limited mastery of chemistry concepts go on to apparently successful careers in nursing also raises the question whether nurses and other biomedical professionals need what chemistry was being taught to them in the first place. This emerging conversation is well summarized by the words of one clinical professor in a distinguished U.S. nursing education program (Day, 2005, p. 1):

> *“This is very interesting and a debate in which I am not at all certain of my position…. One of the questions we have been grappling with is what kinds of background knowledge do nursing students need (natural and social sciences, humanities). Many, but certainly not all, nursing schools require basic general chemistry when the form in which we deal with chemistry in nursing is biochemistry…. One question I am confronted with every summer is can I teach the basics of biochemistry without going through all the abstraction (at least what I perceive as abstraction) you have to go through in basic general chemistry classes. For example, I'm not convinced nurses need to know the details of the periodic table, or things like what a mole is, Avogadro’s number, and stoichiometry…. But, what this translates into in some schools is putting together a chemistry class for nurses that is a way dumbed-down version in which no one learns anything. And I'm certainly not in favor of this.”*

The dilemma of what should be taught and how it should be taught for the biomedical pathways is not a small one for science education and chemistry education in particular, especially given the anxiety of students who fear that the requirements of the sciences may close doors and opportunities. The nursing and medical profession should have a close and realistic look at what chemical skills and concepts their professionals really need and then should come to chemistry instructors, or work with chemistry instructors, and say, “*Please teach our students this.*” It may be that the present situation is that chemistry instructors are told to teach a year of chemistry, including organic and biochemistry and are left much to themselves in working out the details of what, how much, how and when. A practice-appropriate curriculum would not have to be a ‘dumbed down’ version of chemistry, but such a proposal could echo the ideas from Day (above) and perhaps better support student needs. For instance, the valence electron example question described earlier reflects concepts that are quite typical for general chemistry, but deal with concepts that arguably no nurse will ever need to know for a professional career.

Possible solutions to more successful courses, from our perspective, may include changing *how* chemistry is taught to nursing students and others who are non-scientists, such as bringing chemistry instruction more closely into the field locations of nurse clinical practice, with a context-based or guided inquiry approach. Chemistry could be taught in the context of real practice examples relevant to nursing. Then when a topic such as concentration is part of the chemistry curriculum, student nurses could be considering real situations they might find themselves in, such as the difference between two saline solutions at different concentrations that they might be using for an intravenous drip. This would be more appropriate to the working knowledge of nursing practice, and would offer nurses more concrete ways of connecting the chemistry they are learning to their prior knowledge.

The focus could also be placed on changing accreditation requirements and standards for scientific understanding in such biomedical professions as nursing. This could be thought of as changing *what* instruction consists of for students in this population, since the fundamental standards and instructional frameworks might then change. What would need to stay from general chemistry and what could go would have to be carefully considered, so that nurses would have enough knowledge for their work and would be able to continue in their other courses such as physiology and microbiology. But it would be interesting to see what ideas of chemistry nursing instructors really feel are necessary for their students, and whether chemists can come up with ways to successfully help such programs help their students understand what they need to know in this field.

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