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The Colorado Learning Attitudes about Science Survey: Modification and Validation for Use in Chemistry

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Abstract

The chemistry version of the Colorado Learning Attitudes about Science Survey (CLASS-Chem) is a new instrument designed to measure student beliefs about chemistry and about learning chemistry. This instrument is a modification of the original survey (CLASS-Phys) developed and validated for use in physics.*(1)* The chemistry version addresses the same areas of beliefs as the physics version and includes additional belief areas that are characteristic of how experts think about chemistry, such as chemical reactivity and molecular structure. The survey statements are validated using student interviews to ensure clarity in wording and meaning. Statements are grouped into statistically robust categories using the methodology developed during validation of the original physics version. Preliminary results show that most teaching practices cause declines in student beliefs over the course of one semester and that students' self-reported major status correlate with their 'Overall' and 'Personal Interest' score on the survey. It is proposed that this survey can be used to investigate how various teaching methods impact student beliefs, leading to improved learning environments.

Keywords
Chemical Education Research (CER), Testing/Assessment, Quantitative Methods

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I. Introduction

Modern research on science learning describes individuals as active participants in their own intellectual development.*(2)* In line with these findings, chemical education research has focused on placing students at the center of learning. This "student-centered" approach has been the basis of reform efforts in courses from environmental science to physical chemistry.*(3-5)* With these important changes occurring, the need for easy, effective evaluation of the impacts of these changes becomes more pertinent. In addition to any evaluation of the effects on students' content knowledge of chemistry, there is a need to monitor and evaluate the impacts on students' beliefs about chemistry and learning chemistry. Distinct differences exist between novice and expert learners concerning their beliefs about science and learning science, Table 1 summarizes these differences in three main areas. An individual's beliefs shape their own personal experiences on a daily basis. Several studies have shown that students' expectations

Table 1. Contrast of novice and expert beliefs on several dimensions of science (adapted from David Hammer*(6)*).

Novice		Expert
Isolated pieces of information	**content and structure**	Coherent framework of concepts
Handed down by authority. No connection to the real world	**source**	Describes nature. Established by experiment
Pattern matching to memorized arcane recipes.	**problem solving**	Systematic concept-based strategies. Widely applicable.

can be a better predictor of college science performance than previous math or science experience.*(7-9)* Student beliefs can effect how they learn new information; in turn, a student's experience can shape their beliefs.*(2,10,11)* The measurement of student beliefs has been an area of investigation in the physics community for some years,*(1,12-15)* but studies in chemistry are more limited.*(16)*

In order to investigate students' beliefs about chemistry and the learning of chemistry we have modified the Colorado Learning Attitudes about Science Survey (CLASS), originally designed for use in physics.*(1)* The survey is designed to be used in a wide range of undergraduate chemistry courses (from survey courses for non-science majors to graduate level courses); therefore, student interviews were conducted with a broad population of students to ensure clear concise wording and meaning of all statements. The CLASS-Chem survey contains 50 statements which students respond to using a five-point Likert scale (strongly agree to strongly disagree). For example, "I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions". A complete list of statements can be found in the appendix of this paper. Student responses are scored in comparison to expert chemists' responses and grouped into nine categories. In contrast to other survey instruments, our groupings of statements into categories are not predetermined but emerge from student response data and reflect various aspects of student thinking. The statements are grouped and categorized using the modified principal component analysis method (similar to factor analysis) developed during creation of the original CLASS survey.*(1)*

We structure the remainder of this paper as follows. First we introduce the design of our instrument and how it differs from other surveys. We then discuss the scoring and administration of the survey. Next we present the validation and categorization procedures. Finally, we present an example of using the survey to track student beliefs through a range of courses.

II. Instrument Design

While there are many surveys available for probing student beliefs in the physical sciences,*(12,13,15)* there is only one other instrument designed specifically for chemistry, the Chemistry Expectations Survey (CHEMX).*(17)* While both the CHEMX survey and the CLASS-Phys survey (which is the basis for the CLASS-Chem) are originally based on the Maryland Physics Expectation survey (MPEX)*(15)*, they diverge in their goals and methodologies as discussed below.

Since the design of the original CLASS-Phys survey has been described previously,*(1)* only brief details will be given. Statements in the CLASS-Chem survey are written to be meaningful for a range of students and designed to address a wide variety of beliefs about:

(1) learning chemistry
(2) the content of chemistry knowledge
(3) the structure of chemistry knowledge
(4) the connection of chemistry to the real world

The design of the CLASS surveys differs from the MPEX and CHEMX in three main areas. First, wording is carefully selected and tested with students with a range of backgrounds to provide clear concise statements with a single interpretation; MPEX claims only to be valid for use with calculus based courses. Next, CLASS statements do not prompt students' beliefs or expectations about a specific course, but about chemistry in general; many of the CHEMX statements measure students' views about a particular course, including laboratories. We set out to design an instrument for use in all courses, regardless of whether they have a laboratory component. Finally, the grouping of CLASS statements are determined and validated using reduced basis factor analysis, which creates empirically determined groupings of statements based on student responses, the MPEX and CHEMX surveys categorize statements based on predetermined, author-defined groupings.

In creating a chemistry version we first tried merely switching “physics” to “chemistry” in the CLASS survey to create the CLASS-Chem v1, but subsequent interviews with chemistry students revealed that three of these modified statements required some minor wording changes and three other statements were not valid. Student interviews also revealed that with the change of context some statements could not reliably distinguish between novice and expert learners. For example when responding to the statement, “There is usually only one correct approach to solving a chemistry problem”, even the most novice students disagree stating that “there are many different reactions which lead to the same products”. Therefore, in a chemistry context this statement does not provide a useful distinction between learners. The largest modification done when creating version two is the addition of 11 new chemistry-specific statements. Many of the added statements investigate views of chemical reactivity and molecular structure which we consider additional important characteristics of expert thinking about chemistry.

Education in both physics and chemistry challenges students to develop problem solving skills and to form cohesive networks of conceptual ideas. Difficult, and major, components unique to chemistry curriculum involve visualization, reactivity, and molecular structure. All of these concepts are introduced in introductory courses and are developed throughout a wide range of chemistry classes. The visual nature of this material poses unique challenges in learning. Investigations of the beliefs connected to this visual component are a motivating factor in preparing a chemistry specific version of the CLASS survey.

A series of interviews with a range of students produced the additional chemistry-oriented statements for the CLASS-Chem v2 survey. These statements appear in Table II. All statements, including the 42 modified statements from the physics version, have undergone reliability and validation studies (described below) in order to produce the 50 statements currently used in the CLASS-Chem v2. All 50 statements appear in the appendix.

Table II. Chemistry statements added to the CLASS-Chem v2.

2. To understand a chemical reaction, I think about the interactions between atoms and molecules.
11. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.
12. If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior.
17. I can usually make sense of how two chemicals react with one another.
21. Why chemicals react the way they do does not usually make sense to me; I just memorize what happens.
29. When I see a chemical formula, I try to picture how the atoms are arranged and connected.
33. The arrangement of the atoms in a molecule determines its behavior in chemical reactions.
37. In learning chemistry, I usually memorize reactions rather than make sense of the underlying physical concepts.
44. Thinking about a molecule's three-dimensional structure is important for learning chemistry.
48. Spending a lot of time understanding why chemicals behave and react the way they do is a waste of time.
50. When I'm solving chemistry problems, I often don't really understand what I am doing.

III. Scoring and Administration

The scoring and administration is identical to that previously described for the CLASS-Phys survey.*(1)* Brief details will be given here. Students respond to each statement using a five-point Likert scale (strongly agree to strongly disagree). An individual student's 'Overall % favorable' score is the percentage of responses for which the student agrees with the expert's response (including only those statements where experts have consistent views – 45 of 50). Similarly, the 'Overall % unfavorable' score is the percentage of responses for which the student disagrees with the expert. A choice of neutral is neither grouped as favorable nor unfavorable. These individual scores are averaged to determine the 'Overall % favorable' and 'Overall % unfavorable' score for all participating students. Scores and averages are also determined for groupings of statements within categories. Each category contains a number of statements which portray an aspect of student thinking, the determination of this categorization will be addressed in the next section.

While we ask students to respond to statements on a five-point Likert scale, we collapse this scale to a three-point scale (agree/neutral/disagree) during scoring. We have found that utilizing a five-point scale for student responses is important for two reasons.*(1)* First, student interpretations of agree vs strongly agree are not consistent, the same belief may elicit a strongly agree response for one student and only an agree response for another. Second, students state that without this distinction they would have chosen neutral more often. We realize that some information is lost by grouping strongly agree with agree (and strongly disagree with disagree), however, this collapsed scale greatly simplifies the interpretation and processing of the data and perserves the primary goal which is to provide comparisons to 'experts' general responses (agree or disagree). An additional goal of the survey is that it is widely used among faculty, therefore, simplicity of scoring and interpretation is an important consideration.

The CLASS-Phys survey has been administered since fall 2003 and the CLASS-Chem survey since fall 2004 (v1) and summer 2005 (v2). To date, over 5000 students in over 30 courses at CU-Boulder have taken the CLASS-Chem. Currently, two other universities are also using the survey. We administer the survey online and have been successful in maximizing student responses by utilizing the following approach: (1) the survey is announced in class by the instructor and the HTML link is posted on the course web site; (2) students are contacted via email and given a 5-7 day window to submit their survey, a follow-up email is sent a few days from the end of the window to those who have not submitted; (3) whenever possible, a small amount of credit is offered for participation as we have seen that the small credit increases participation significantly (e.g. matched data, defined below, increased from 40% to 60% of enrolled students in a large (>800 student) 1st term chemistry course). Students may receive this credit for simply submitting their name and ID number, but very few choose this option.

The number of responses actually scored is less than the total number of submissions for many reasons. Student responses are not scored if the same answer is chosen for essentially all statements, or if a student takes less than three minutes to complete the survey on-line. In addition, we have added a statement to reject those students who randomly choose answers. Statement 31 is used to identify these students, "We use this statement to discard the survey of people who are not reading the statements. Please select agree (not strongly agree) for this statement."

On average, we have about a 75-85% response rate on the survey with roughly 10-15% of these responses being dropped for the above reasons; the remaining responses provide useful pre and post data. In order to evaluate shifts in beliefs from pre to post, we compile a subset of data, "matched data" which consists of only students who have successfully completed both pre and post surveys. This approach ensures that the calculated changes reflect shifts in student thinking rather than changes in populations.

V. Validation

The CLASS-Chem survey has undergone extensive validation studies. It is important to point out the criteria we believe an instrument must meet in order to be considered valid. First, the wording and meaning of the statements within the survey must be clear to the target population. In addition, students' responses (either 'expert' or 'novice') must be consistent with their explanation for why they chose that response. Second, the statement answers must be agreed upon by experts, providing face validity to the survey. Next, the grouping of statements into categories used to characterize the thinking of the student population must be statistically robust – that is, responses to the individual statements are reasonably correlated with one another. Lastly, the instrument must demonstrate the ability to distinguish between groups that should be distinguishable in theory – for example, between the beliefs of non-science majors and chemistry majors. The statements in CLASS-Chem v2 are validated through interviews with chemistry students as well as with chemistry faculty. The faculty responses are also used to establish the expert opinion. Statement groupings are validated using Principle Component Analysis*(18)* on student responses.

A. Interviews

During development of the original CLASS survey, over forty students were interviewed.*(1)* This series of interviews with students in various physics courses, many of which were concurrently enrolled in chemistry courses as well, established the wording and content for the initial statements used on the survey. In addition to these interviews, ten students in a range of courses – from chemistry for non-majors to junior level organic chemistry – were interviewed during development of the chemistry version. Students were selected to provide a diverse group in terms of gender, race, and major. The interview process consisted of three parts. First, the students completed a pencil and paper version of the survey. Once completed, students were asked about their major, course load, educational interests, good/bad class experiences, and future goals. These statements provided information to characterize the student and their interest as well as put the student at ease by engaging in familiar conversation. The bulk of the interview consisted of the interviewer reading the statements while the student looked at a written version. Students were asked to respond to each statement using the five-point Likert scale and then to reflect on any thoughts prompted by the statement. Most students freely provided thoughts and comments on all statements; those that did not were prompted to explain their answer choice. If questions were asked by the student about a statement or the interview itself, they were not addressed until the very end of the interview session.

1. CLASS-Phys Statements

Student interviews resulted in minor wording changes in two statements (#'s 27 and 32) and the complete removal of only 3 out of the original 42 CLASS-Phys statements (one was not scored in the CLASS-Phys and the other two were scored but not included in any specific CLASS-Phys category). Students expressed some confusion as to the original context of statements 27 and 32. The confusion was due to the fact that the words "equation" and "formula" are readily interchangeable in physics and have the same mathematical meaning; in chemistry, however, these words do not have the same meaning and hence are not interchangeable. An "equation" in chemistry can be either the mathematical type, as in physics, or the chemical type. A "chemical equation" is a format for writing a chemical reaction*(19)* and differs from a "chemical formula" which is a format for listing the number and kind of constituent elements in a compound.*(19)* If a statement did not obviously indicate which form of the words was being used, then the prefix "chemical" or "mathematical" was attached. For example in the statement, "spending a lot of time understanding where formulas come from is a waste of time," the word "formula" was replaced with "mathematical formula". This provided unambiguous interpretations for most of the statements.

Based on the student interviews, the three statements below were removed from CLASS-Chem v1.

--*There is usually only one correct approach to solving a chemistry problem.*
--*There could be two different correct values for the answer to a chemistry problem if I use two different approaches.*
--*It is possible for chemists to carefully perform the same experiment and get two very different results that are both correct. (Not scored on CLASS-Phys)*

The first statement was removed because in a chemistry context it is readily obvious to even the most novice students that there are many approaches to solving a chemistry problem, for example, students learn a number of various reaction pathways to produce the same product. In the case of the physics version, the novice learners tended to agree with the statement and 'experts' disagreed, providing a measure of discrimination between ‘novice’ and ‘experts’. The second statement had similar problems with students referring to reaction pathways. The third statement, which is scheduled for revision or replacement in the physics version due to lack of a consistent expert response, posed difficulties with the less experienced students. Many students stated that there may be “unconsidered variables” or that there were “a lot of twists in chemistry that break the rules”. During interviews students would also reflect on past laboratory experiments where “everyone followed the same procedure” but the results were very different. Based on these comments, and the fact that these specific statements were not grouped into any of the eight categories in the physics version, we removed all three statements. Dropping these statements also made room for more additional statements as we did not want to exceed a total of 50 statements.

2. Chemistry-specific Statements

Using student interviews, we tested over twenty candidate statements to probe the additional chemistry-specific areas of students’ beliefs, including some statements selected from the CHEMX and some inspired by or revised through student interviews. 17 statements proved to be valid in interviews and we kept the 11 we felt were most informative. Many statements were revised based on vocabulary problems. It was discovered that words such as “intuitive”, “theories”, and “structure” do not have unambiguous definitions for introductory students. It was found that the word “structure” must be associated with either molecular or electronic in order to have singular meaning to many students.

B. Faculty Surveys

The 50 statements selected for the CLASS-Chem v2 survey were given to over 20 chemistry faculty at four different universities. This data was used to confirm the expert response and also to provide additional feedback about the statements themselves. Forty-five of the statements had consistent expert responses. These responses (agree or disagree) are included in the appendix. Using these responses to define the 'expert' view, we scored the individual faculty surveys using the same approach as used for student responses. Figure 1 plots the faculty's average '% Favorable' vs '% Unfavorable' scores for 'Overall' and each category. For the 45 statements which comprise the 'Overall' score, the faculty surveyed score 89.2% favorably and only 3.2% unfavorably.

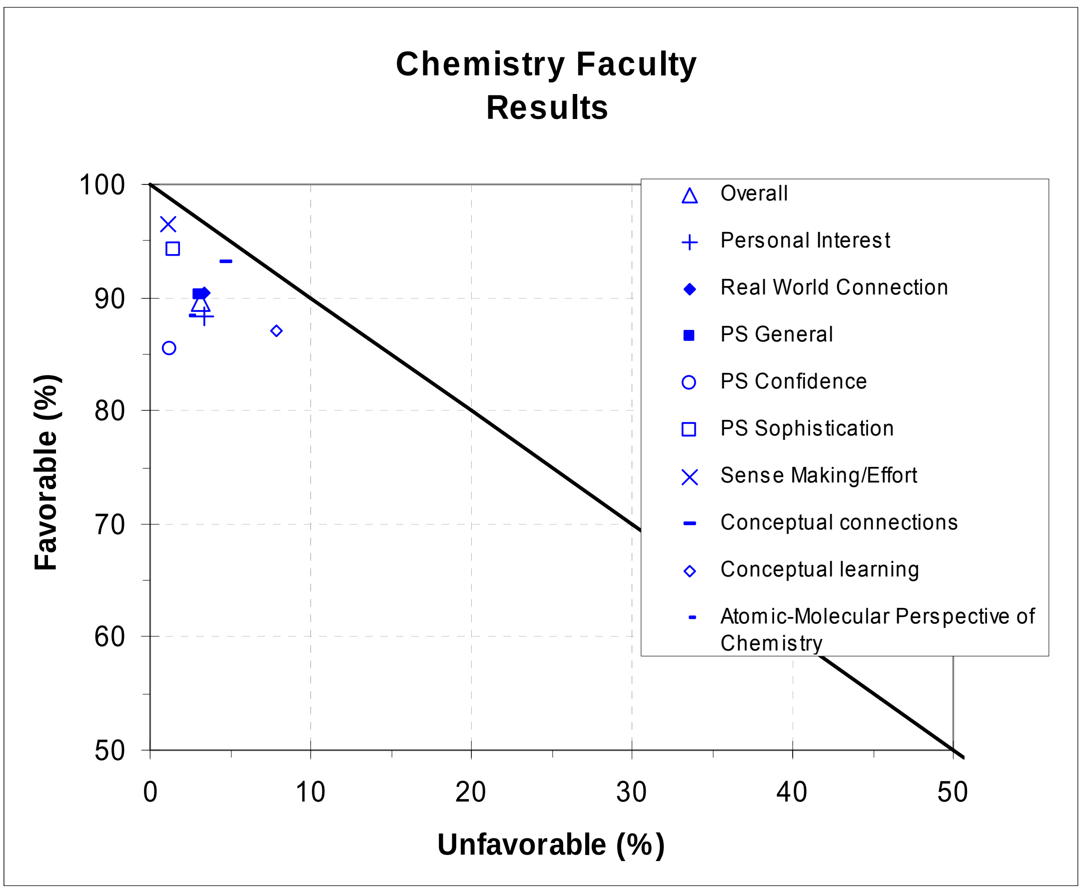

Figure 1. % Favorable vs % Unfavorable plot of faculty responses.

Four of the five un-scored statements do not have consistent faculty responses and gauge either nature of science (#8) or learning style aspects (#s 5,10,39). We include these learning style statements in the survey because they provide useful information about student approaches to learning. Developing suitable nature of science statements is an ongoing area of investigation; statement #8 will be revised or replaced in a future version. The last un-scored statement is number 31; this statement, as described earlier, is used during the scoring process to reject surveys submitted with random guesses.

C. Categorization of Statements

A significant difference between the CLASS surveys and MPEX or CHEMX is the method by which the statement groupings are determined. The categories in the MPEX or CHEMX surveys are defined a priori by the developer without the use of statistical methods to ensure their validity. During the development and validation of the physics version of CLASS, a substantial number of students were given the MPEX survey. Upon statistical analysis, it was found that some groupings were made up of statements with very weak correlations (<0.05). If statement groupings are to be used in characterizing facets of student thinking, then the student responses to the statements within that grouping should be reasonably correlated (>0.15) if in fact, the groupings represent student thinking. If statistical analysis is not used to determine correlated student responses, it is very unlikely that predetermined categories will be made of statements which reflect student thinking.

1. Categorization Philosophy and Approach

The details of our categorization are presented in the previous CLASS-Phys validation paper;*(1)* a brief summary will be given here. Categories can be established using two different philosophies, either "raw statistical" or "predetermined". In the raw statistical approach, no constraints are in place and categories emerge from the data via exploratory factor analysis.*(20-22)* In contrast, a predeterministic approach bases categories on expert perspectives about how statements should be grouped. Both of these approaches have strengths and weaknesses.*(1)*

Our approach combines the strengths of both methods, providing an optimum set of valid categories. Figure 2 (courtesy of Adams *et al.*) summarizes the iterative process used in choosing categories, a detailed description of the process can be found in the work of Adams *et al.(1)* Several indicators of statistical validity are evaluated in

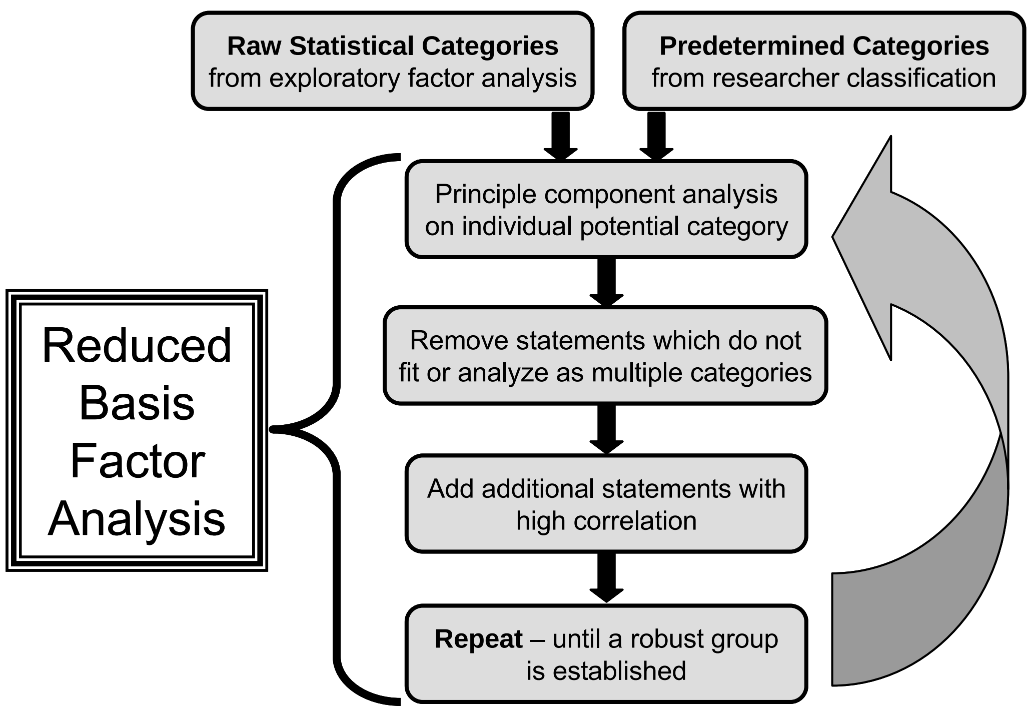

Figure 2. Flow chart depicting reduced basis factor analysis.

determining the strength of each statement grouping. To facilitate comparison between various groupings, a robustness calculation is used to assign a value for each group. Optimization of this value provides a robust, statistically valid grouping of statements. The robustness calculation looks at the output of doing a factor analysis on each set of statements in a category. This criterion is determined by evaluating various indicators of statistical validity including the correlation coefficients between statements, the percent of variance explained by the weighted combination of statements represented by the first factor and the factor loadings for each statement in that first factor. (A factor analysis always produces as many factors/components as statements in the basis.) The robustness number for a grouping is calculated using the following equation:

$$\text{Robustness} = (2cc + fl + 5|\Delta E|/N) \times 3R^2$$

where cc is the average absolute value of the correlation coefficients between statements, fl is the average absolute value of the factor loadings for the category, ΔE represents the shape of the scree plot (see Fig. 3 for details), N is the number of statements in the category, and R^2 is the Pearson product moment correlation, which represents the linearity of the scree plot components beyond the first component. Values used to calculate robustness for the 'Real World Connection' category can be found in Table III. The total variance calculations are based on the slopes of the scree plot in Fig. 3.

Table III. Data from optimized 'Real World' Category

	Statement Correlation Matrix				Category Values	
	S34	**S36**	**S41**	**S43**	**Robustness**	9.68
S34	1.00	0.45	0.43	0.35	**cc**	0.39
S36	0.45	1.00	0.35	0.42	**fl**	0.74
S41	0.43	0.35	1.00	0.33	**ΔE***	-1.37
S43	0.35	0.42	0.33	1.00	**N**	4
Factor Loadings			Total Variance*		**R^{2*}**	0.99
S34	0.76		**Slope 1-2**	-1.47		
S36	0.76		**Slope 2-4**	-0.09		
S41	0.71					
S43	0.71					

*Based on scree plot (A) in Fig. 3

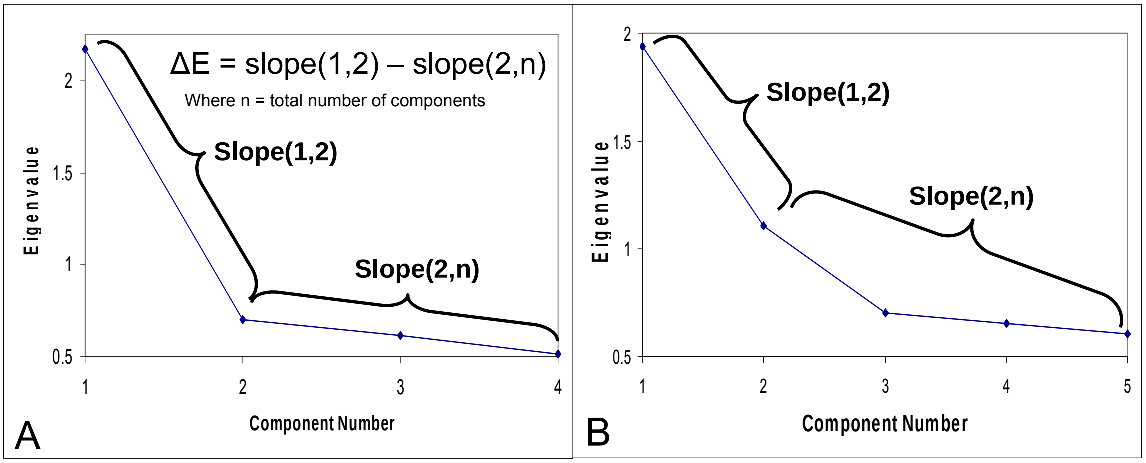

Figure 3. Scree plots from good category (A) and a poor category (B).

2. Unmodified Physics Categories

The initial implementation of the CLASS survey in chemistry courses consisted of simply changing the word "physics" to "chemistry" in all the statements. Before modification of any categories proceeded, the robustness of the eight original categories was measured and compared to those published.*(1)* From the comparison of post semester data in Table IV, we see that the statement groupings produce nearly equal robustness values for each category regardless of the statement context (physics vs chemistry).

Table IV. Comparison of robustness values for the eight categories of the CLASS-Phys survey with both physics and chemistry students.

Category	CLASS-Phys	CLASS-Chem v1
Personal Interest	8.20	7.74
Real World Connections	7.32	9.68
Problem Solving-General	6.50	6.44
Problem Solving-Confidence	7.39	6.60
Problem Solving-Sophistication	8.25	8.00
Sense Making/Effort	5.91	4.94
Conceptual Connections	5.57	4.31
Applied Conceptual Understanding	5.71	5.30

In validation of the physics version,*(1)* the lowest acceptable robustness value was set at five. The consistent robustness of the categories between these two populations is a strong affirmation of the universality of the statements and our grouping procedure. With these categories and values as a start, we set out to investigate the series of additional statements.

3. CLASS-Chem Categories

The iterative process using reduced basis factor analysis depicted in Figure 2 was used to optimally incorporate the 11 additional statements into the chemistry survey. The final CLASS-Chem v2 categories and robustness factors are listed in Table V. These categories are quite similar to the original CLASS-Phys categories. The additional

Table V. CLASS-Chem v2 categories, statement numbers, and post robustness values. **Bold** indicates added statements in v2.

Categories	Statement Numbers	Robustness
Personal Interest	4,13,16,28,34,36	7.74
Real World Connection	34,36,41,43	9.68
Problem Solving: General	15,18,19,**21**,28,30,40,47,49,**50**	7.16
Problem Solving: Confidence	18,19,40,47	6.60
Problem Solving: Sophistication	6,24,25,28,40,47,**50**	8.48
Sense Making/Effort	13,**21**,26,27,38,42,46,**48**,49	6.17
Conceptual Connections	6,7,15,24,**37**,38,**50**	6.01
Conceptual Learning	1,6,7,**12**,24,25,47	6.71
Atomic-Molecular Perspective of Chemistry	**2**,**11**,**17**,**29**,**33**,**44**	7.13

statements are spread over five original categories and one new category not in the physics version. Statements 1 and 9 were removed from the ‘Conceptual Connections’ and ‘Conceptual Learning’ categories, respectfully, because of poor correlation with the other category statements. The remaining original statements all strengthened each category to the same degree as in the physics version or more.

With the addition of these statements, the category names were reviewed. It was found that in all but one instance, the names chosen for the physics categories reflected the overall theme of the statements grouped within them, the exception being that the 'Applied Conceptual Connections' category was renamed 'Conceptual Learning'. One new category named 'Atomic-Molecular Perspective of Chemistry' was added and contains six of the additional statements. Only 36 out of the 45 statements with 'expert' responses are factored into one or more of the categories. This demonstrates the usefulness of the categorization scheme used. For example, we expected that statement #35: "To learn chemistry, I only need to memorize how to solve sample problems," would fit into one of the problem solving categories, but the analysis revealed it did not correlate with the other statements in these categories and hence did not describe student thinking in these areas.

D. Concurrent Validity

The CLASS survey is designed to measure students' beliefs about chemistry and the learning of chemistry. Therefore, an appropriate concurrent validity test would be to show that the instrument can measure a difference in beliefs between populations which should have different beliefs. Figure 4 shows the percentage of favorable responses for the 'Overall' statements and those in the 'Personal Interest' category. It is expected that students' overall and personal interest scores should correlate with course selection. For example, one would not expect a student taking an introductory course for non-majors to have a strong personal connection to the discipline, in contrast to a chemistry major taking a junior level physical chemistry course. Not only does the survey distinguish between these different populations, but it can also differentiate student populations within the same course as shown in Figure 4. Students in both general and organic chemistry who are chemistry majors show more expert-like beliefs than the non-chemistry majors (made up of biology majors, non-science majors, or other science majors) in these same courses.

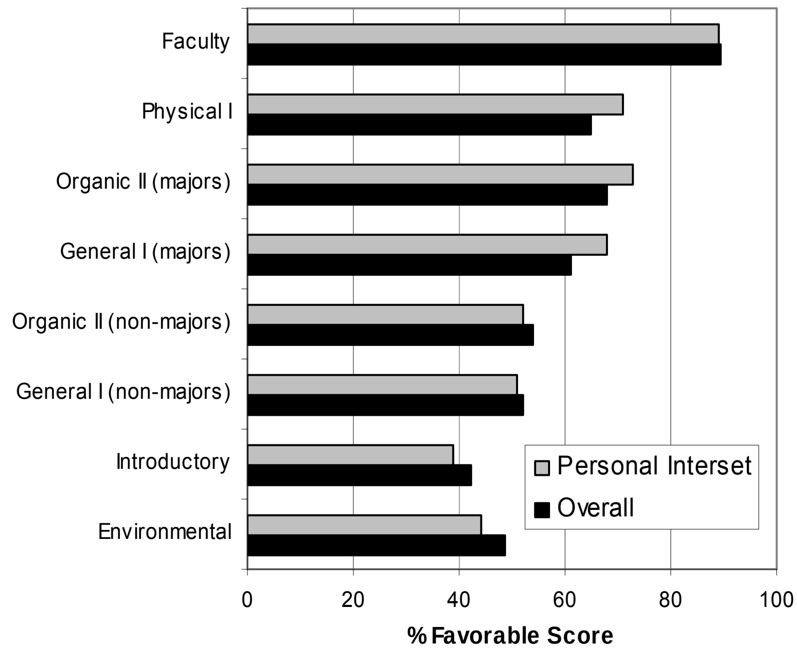

Figure 4. Comparison of percent favorable scores for 'Personal Interest' and 'Overall' categories for a range of courses and majors including faculty.

E. Test-Retest Studies

In order to gauge the reliability of the CLASS instruments we use the test-retest method.*(23,24)* Reliability was measured using pre responses from two general chemistry I courses during the fall 2005 and fall 2006 semesters. Since it is reasonable to assume there is little variation in these large (N>800) student populations from year to year, this provides a good direct measure of survey reliability. The correlations shown in Table V., of the percent favorable, percent neutral, and percent unfavorable scores for all statements on the CLASS-Chem v2, show that student responses between the two years are very similar. Data from the physics version is also presented in Table V for comparison. We feel that this is a better measure than calculating a Cronbach alpha value*(23,24)* for this type of instrument for two reasons. First, because we have large

Table V. Correlation of percent favorable, neutral, and unfavorable scores from fall 2005 to fall 2006 general chemistry I courses and fall 2004 to spring 2005 algebra-based physics I.

	%Favorable	%Neutral	%Unfavorable
Chemistry	0.99	0.95	0.99
Physics	0.98	0.88	0.98

and very consistent student populations from one year to the next in these large courses, the retest-approach provides the most direct test of reliability. Second, the Cronbach alpha test relies on correlations between statements, and we intentionally exclude statements with a very high degree of correlation, in order to obtain the maximum amount of information from a given number of statements. We did calculate the average Cronbach alpha value, using fall 2006 data from nine chemistry course at two different universities, for CLASS-Chem v2 to be 0.89. While this value is high and falls into the 'good' range,*(25)* it is not so high that it suggests repetition within the survey statements. Streiner *et al.* state in their work on measurement scales that "if alpha is too high, then it may suggest a high level of item redundancy; that is, a number of items asking the same question in slightly different ways."*(26)*

VI. Applications

The breadth of data collected with the CLASS survey can be analyzed in a variety of different ways to extract specific results. Using physics data, our group has studied the correlation of students' self-reported interest in physics to their surveyed beliefs*(27)* as well as differences in beliefs with gender*(1)* and correlations between beliefs and content learning.*(28)* Using the common statements between CLASS-Phys and CLASS-Chem we compared how biology majors view each discipline.*(29)* In addition to characterizing students' beliefs, shifts in beliefs over the course of a semester can be correlated to various teaching methods. The general trend in shifts for both physics and chemistry are in the negative direction, meaning the students score more favorably at the start of a semester than at the end. Table VI. shows pre and post scores along with calculated shifts for a general chemistry I. This trend is a current topic of investigation as its cause can stem from a variety of sources. We do have data from two physics courses which do not show a decline in beliefs. These instructors made modest efforts to address student beliefs over the course of the semester, suggesting that such undesired impacts of instruction are relatively easy to change. Obtaining large positive shifts in beliefs has been challenging and is an area of ongoing research in the physics community.*(30)*

Table VI. General chemistry I: Results show decline in percent favorable scores over one semester.

Category	PRE	POST	SHIFT	Std. Error*
Overall	53	48	-5	1
Personal Interest	53	44	-9	2
Real World Connection	58	46	-12	2
Problem Solving: General	59	53	-6	2
Problem Solving: Confidence	64	56	-8	2
Problem Solving: Sophistication	44	40	-4	2
Sense Making/Effort	66	56	-10	1
Conceptual Connections	55	51	-4	2
Conceptual Learning	42	40	-2	2
Atomic-Molecular Perspective of Chemistry	52	51	-2	2

*Standard Error in SHIFT calculation

VII. Conclusions

This paper describes the modification and validation of the CLASS-Phys survey for use in chemistry courses. The CLASS-Chem v2 consists of 50 statements, 39 slightly-modified statements from the CLASS-Phys survey plus eleven additional statements. Validation has been performed for all statements to ensure clarity in wording and meaning for a wide group of students. Statements are categorized into statistically robust groupings which are useful to educators in evaluating various aspects of student thought.

This work establishes an instrument which can be used to study student beliefs about chemistry and the learning of chemistry. This instrument is a useful tool for evaluating the impacts of teaching practices. The impacts of instruction on reducing interest in chemistry are particularly worth noting if one is concerned with increasing the number of students majoring in chemistry.

Copies of the CLASS-Phys and CLASS-Chem surveys can be found online and in PDF format at http://CLASS.colorado.edu. Excel scoring templates are also available from the same address.

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Appendix: CLASS-Chem v2 Statements
Letter before statement number indicates 'expert' response,
where **D** = disagree, **A** = agree, and **NS** = not scored.

	Statements
D	1. A significant problem in learning chemistry is being able to memorize all the information I need to know.
A	2. To understand a chemical reaction, I think about the interactions between atoms and molecules.
A	3. When I am solving a chemistry problem, I try to decide what would be a reasonable value for the answer.
A	4. I think about the chemistry I experience in everyday life.
NS	5. It is useful for me to do lots and lots of problems when learning chemistry.
D	6. After I study a topic in chemistry and feel that I understand it, I have difficulty solving problems on the same topic.
D	7. Knowledge in chemistry consists of many disconnected topics.
NS	8. As chemists learn more, most chemistry ideas we use today are likely to be proven wrong.
D	9. When I solve a chemistry problem, I locate an equation that uses the variables given in the problem and plug in the values.
NS	10. I find that reading the text in detail is a good way for me to learn chemistry.
A	11. I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions.
D	12. If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior.
A	13. I am not satisfied until I understand why something works the way it does.
D	14. I cannot learn chemistry if the teacher does not explain things well in class.
D	15. I do not expect equations to help my understanding of the ideas in chemistry; they are just for doing calculations.
A	16. I study chemistry to learn knowledge that will be useful in my life outside of school.
A	17. I can usually make sense of how two chemicals react with one another.
A	18. If I get stuck on a chemistry problem on my first try, I usually try to figure out a different way that works.
A	19. Nearly everyone is capable of understanding chemistry if they work at it.
D	20. Understanding chemistry basically means being able to recall something you've read or been shown.
D	21. Why chemicals react the way they do does not usually make sense to me; I just memorize what happens.
A	22. To understand chemistry I discuss it with friends and other students.
D	23. I do not spend more than five minutes stuck on a chemistry problem before giving up or seeking help from someone else.
D	24. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.
D	25. If I want to apply a method used for solving one chemistry problem to another problem, the problems must involve very similar situations.

D	26. In doing a chemistry problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.
A	27. In chemistry, it is important for me to make sense out of mathematical formulas before I can use them correctly.
A	28. I enjoy solving chemistry problems.
A	29. When I see a chemical formula, I try to picture how the atoms are arranged and connected.
A	30. In chemistry, mathematical formulas express meaningful relationships among measurable quantities.
NS	31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question.
D	32. It is important for the government to approve new scientific ideas before they can be widely accepted.
A	33. The arrangement of the atoms in a molecule determines its behavior in chemical reactions.
A	34. Learning chemistry changes my ideas about how the world works.
D	35. To learn chemistry, I only need to memorize how to solve sample problems.
A	36. Reasoning skills used to understand chemistry can be helpful to me in my everyday life.
D	37. In learning chemistry, I usually memorize reactions rather than make sense of the underlying physical concepts.
D	38. Spending a lot of time understanding where mathematical formulas come from is a waste of time.
NS	39. I find carefully analyzing only a few problems in detail is a good way for me to learn chemistry.
A	40. I can usually figure out a way to solve chemistry problems.
D	41. The subject of chemistry has little relation to what I experience in the real world.
A	42. There are times I solve a chemistry problem more than one way to help my understanding.
A	43. To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed.
A	44. Thinking about a molecule's three-dimensional structure is important for learning chemistry.
A	45. It is possible to explain chemistry ideas without mathematical formulas.
A	46. When I solve a chemistry problem, I explicitly think about which chemistry ideas apply to the problem.
D	47. If I get stuck on a chemistry problem, there is no chance I'll figure it out on my own.
D	48. Spending a lot of time understanding why chemicals behave and react the way they do is a waste of time.
A	49. When studying chemistry, I relate the important information to what I already know rather than just memorizing it the way it is presented.
D	50. When I'm solving chemistry problems, I often don't really understand what I am doing.