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CHEMX: An Instrument To Assess Students' Cognitive Expectations for Learning Chemistry

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In 2001, this *Journal* published a symposium of papers examining the interface between learning theory and chemistry education *(1).* One commonality among the differing theories is the important role that prior knowledge plays both in facilitating and impeding students' learning chemistry—not just prior knowledge about fundamental chemistry concepts, but also knowledge about how learning happens. Ausubel and Novak postulate that learning takes place when students make connections between what they already know and what they need to know *(2–5),* and a rich literature exists that describes the prior knowledge of chemistry that students bring to their study, including misconceptions *(6–12).* However, the second dimension of prior knowledge—that is, learning about learning—remains largely unexamined in chemistry education. This research describes the development of a quantitative measure to explore this second dimension of students' prior knowledge, focusing specifically upon the collection of attitudes and beliefs about learning known as *cognitive expectations,* a construct coined by Redish, Saul, and Steinberg (*13,* p 213; emphasis in original):

> It is not only physics concepts that a student brings into the physics classroom. Each student, based on his or her own experiences, brings to the physics class a set of attitudes, beliefs, and assumptions about what sorts of things they will learn, what skills will be required, and what they will be expected to do….[W]e will use the phrase *expectations* to cover this rich set of understandings. We focus on what we might call students' *cognitive expectations*—expectations about their understanding of the process of learning physics and the structure of physics knowledge rather than about the content of physics itself.

Previous Research: The MPEX Survey

Physics education researchers have argued that cognitive expectations play an important role in the ultimate success that students achieve in any particular course *(13).* Students use these expectations to shape the attitudes they bring with them into the classroom, for example, to decide such things as how frequently to attend class, how much time and effort to spend working on assignments, and even what to attend to during class. In 1998, Redish and co-workers developed MPEX (Maryland Physics Expectations Survey), a survey that measures cognitive expectations for physics.

MPEX contains 34 items divided into six clusters, each representing a distinct dimension of expectations about learning: independence, coherence, concepts, reality link, math link, and effort. Initially administered to students enrolled in calculus-based physics ($N = 1500$), the MPEX survey results showed a statistically significant gap in cognitive expectations between teachers and learners of physics. Guided by Perry's research on the cognitive development of college students *(14–16),* Redish's hypothesis was that this gap would close over time. However, the gap between student and faculty expectations widened further over the course of a semester.

Research Questions

Given the surprising findings of Redish's study, the question arose as to whether a similar phenomenon existed in chemistry. How is the domain of student expectations characterized with regard to learning chemistry? How do student expectations for learning chemistry change across the undergraduate chemistry curriculum? How do such expectations compare to those of chemistry faculty? These research questions led to the development of CHEMX, the Chemistry Expectations Survey and the research study that is described below.

Development of CHEMX

While there are certainly parallels between learning chemistry and learning physics, the two disciplines are not isomorphic with one another. In order to assure the reliability and validity of CHEMX, we could not default to using MPEX and merely change any occurrence of the word "physics" to "chemistry". Rather than focus on whether an MPEX item should be either deleted or modified for CHEMX, we sought evidence to include each individual item (see Reliability below). Some MPEX items were not included because they were idiosyncratic to physics, not chemistry. Other MPEX items required modification to be representative of learning chemistry. Considerable thought was also given to what defining characteristics of learning chemistry were not represented in the MPEX instrument. In particular, the construct first described by Johnstone *(17)* connecting the macroscopic, particulate, and symbolic domains, and the essential skill of visualization *(18–20)* were both lacking.

The CHEMX Instrument

CHEMX consists of 47 statements divided into seven clusters (effort, concepts, math link, reality link, outcome, laboratory, and visualization) and uses a standard five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The survey has 25 items that are based upon MPEX statements while the other 22 are original statements written by the authors specifically for CHEMX.

Each CHEMX cluster is characterized by two opposing dimensions. The expectation about learning chemistry most commonly held by chemistry faculty is designated as "favorable" while the opposite view is designated as "unfavorable". The specific items that constitute each cluster are listed in Table 1. A full copy of the CHEMX instrument is included in the Supplemental Materials.$^{\mathrm{W}}$

Scoring the CHEMX Responses

Of the 47 items in CHEMX, 25 are worded negatively (indicated by bold face numbers in Table 1); that is, a favorable response would be indicated by answering strongly disagree. All items in bold face in Table 1 were re-coded, meaning that the theoretically possible score on CHEMX ranges from a minimum of 47 to a maximum of 235. The higher a student's score on CHEMX, the more the student's expectations align with the favorable views presented in Table 1. Eight additional demographic questions are included to assist with exploratory data analysis.

Reliability of CHEMX

Establishing the reliability of an instrument permits a researcher to attribute any changes in participant responses across time to changes in the respondents themselves, not inconsistencies in the instrument *(21)*. Reliability was established both for individual items and for the existence of clusters using inter-item correlations, calculation of values for Cronbach's α (values of 0.7 or greater indicate an acceptable reliability: see ref *21*), and factor analysis using data from chemistry faculty respondents ($N = 157$).

Table 1 lists the Cronbach's α values for each CHEMX cluster; the range is 0.73–0.89. Furthermore, the reliability of the overall survey is exceptionally good with a Cronbach's α value of 0.97. The fact that the overall Cronbach's α value is greater than the Cronbach's α value of any individual cluster also attests to the robustness of CHEMX *(22)*. Factor analysis results indicate that the statements in the visualization, concepts, and reality link clusters loaded into distinct and separate factors. Although the statements in the remaining

Table 1. Favorable and Unfavorable Dimensions of the Seven CHEMX Clusters

Cluster	Favorable View	Unfavorable View	Representative Statement	CHEMX Items	Cronbach's α Values
Effort	Makes the effort to use information available and tries to make sense of it	Does not attempt to use available information effectively	"I read the text in detail and work through many of the examples given there."	2, **6,** 8, **19,** 22, **31, 34, 38,** 41	0.85
Concepts	Stresses understanding of the underlying ideas and concepts	Focuses on memorizing and using formulas	"When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problems."	**4, 28,** 36, **37,** 43	0.73
Math Link	Considers mathematics as a convenient way of representing physical phenomena	Views chemistry and mathematics as independent with little relationship between them	"In this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens."	**5, 9,** 11, **21, 29**	0.82
Reality Link	Believes ideas learned in chemistry are relevant and useful in a wide variety of real contexts	Believes ideas learned in chemistry have little relation to experiences outside the classroom	"It is unnecessary for me to have to relate chemistry to the real world."	**14,** 26, **30,** 35, 42	0.86
Outcome	Believes learning chemistry is essential to ultimate career goals	Believes chemistry is simply another obstacle to endure before getting to the "important" material	"Only a very few specially qualified people are capable of really understanding chemistry."	7, 15, **16, 17, 25,** 40, **45,** 47	0.82
Laboratory	Stresses importance of understanding chemical concepts behind experiments	Views laboratory experiments as steps to follow and data to collect with little connection to lecture	"I really don't expect to understand how laboratory instruments work—they are just tools that help me complete the lab."	**1, 12,** 13, **23, 32,** 39, **44, 46**	0.82
Visualization	Considers visualization of atoms and molecules in 3-D essential to learning chemistry	Views visualization as unnecessary for learning chemistry	"Solving a chemistry problem may require me to be able to draw molecules in more than one way."	3, 10, **18,** 20, 24, 27, 33	0.89

Note: CHEMX item numbers shown in bold are negatively worded statements that need to be recoded for data analysis.

four clusters loaded into more than one factor, the overlying structure of these clusters was retained based upon the high Cronbach's α values and strong inter-item correlations.

Data Collection

An online version of CHEMX was administered to a stratified random sample of faculty members from 50 chemistry departments across the country. Faculty were asked to respond as they would *prefer* their students to respond, not as they might *predict* their students would respond. Faculty (N = 157) self-identified with the following disciplines: analytical chemistry (N = 25), biochemistry (N = 22), chemistry education (N = 5), inorganic chemistry (N = 25), organic chemistry (N = 39), and physical chemistry (N = 41).

Undergraduate students from four institutions were surveyed over a nine-month period. These particular institutions were purposefully sampled *(23)* based on differences in their selectivity in the admissions process to serve as a proxy for the prior study of chemistry a student would likely bring to the institution. The four institutions represented: a highly selective, liberal arts college (LA, N = 100); a selective, small public university (SP, N = 342); an open-admission, medium-sized university (OP, N = 131); and a public community college (CC, N = 24). All faculty and student respondents were provided with information regarding their rights as human subjects. Informed consent was secured from all the respondents.

Results

Faculty Expectations

Figure 1 presents the averaged faculty results in the form of an agree–disagree plot. Introduced by Redish and co-workers *(13),* an agree–disagree plot shows the percentage of favorable responses indicated by each respondent group versus the percentage of unfavorable responses. Responses are characterized as favorable, unfavorable, or neutral and must sum to 100% across these three categories; therefore the space of possible responses lies in the triangle bounded by the origin and the points (0, 100) and (100, 0). The horizontal distance between any point and the diagonal line from (0, 100) to (100, 0) represents the percentage of neutral responses indicated by the respondents. For example, in Figure 1, chemistry education researchers (represented by the triangle) indicated approximately 92% favorable responses, approximately 4% unfavorable responses, and approximately 4% neutral responses.

A visual inspection of the agree–disagree plot in Figure 1 reveals that with the exception of chemistry education faculty, there appear to be few differences among faculty members of the traditional disciplines of chemistry with regards to their expectations for student learning. Independent samples t-tests were performed to determine whether any statistically significant differences existed among the six disciplines. The t-test results showed that chemistry education researchers scored significantly higher (p values for each comparison have a range of 0.016–0.049) than their counterparts in the other disciplines of chemistry.

These results are consistent with the belief that individuals who closely study student learning should score higher on an instrument designed to measure one dimension of that learning. Beyond chemistry education researchers, however, few significant differences emerged among faculty of the five traditional chemistry subdisciplines. In fact, of the nearly 125 comparisons made between faculty in these five traditional subdisciplines, only two were significant: math link cluster results of analytical chemists compared with physical chemists (t = −2.052, p = 0.044) and visualization cluster results of analytical chemists compared with organic chemists (t = −2.133, p = 0.037).

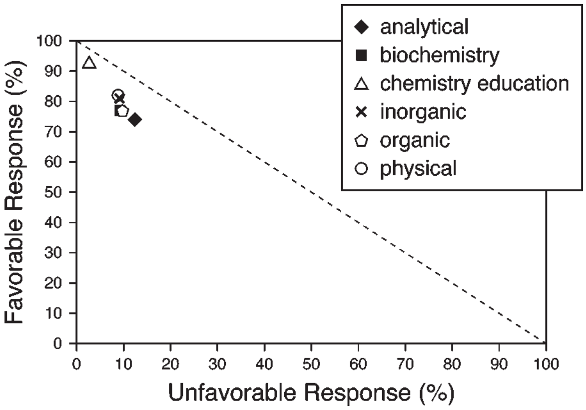

Figure 1. Agree–disagree plot of overall chemistry faculty results.

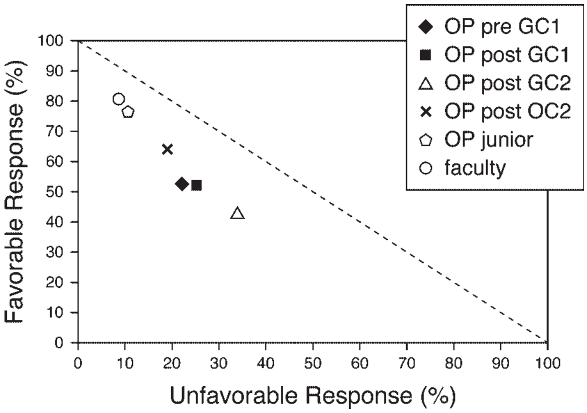

Figure 2. Agree–disagree plot of open-admission university (OP) student results.

Student Expectations

An agree–disagree plot for averaged student responses from an open-admission university is shown in Figure 2. The legend indicates results prior to and after general chemistry (GC1 and GC2, respectively); after completing a year of organic chemistry (OC); and at the end of the junior year chemistry curriculum. (Data from graduating chemistry majors were unavailable.) The averaged chemistry faculty response is indicated by a circle in the upper left corner of the plot. Student expectations about learning chemistry increased in percentage of favorable responses and decreased in percentage of unfavorable responses from the time students first began general chemistry until they completed their junior

Table 2. Agree–Disagree Summary Results by Learning Institution Type

Students' Chemistry Course Status at Time of Survey	Favorable, Unfavorable, and Neutral Student Responses, Respectively, in Percent			
	Open-Admission Public Community College (N = 24)	Open-Admission Medium-Sized Public University (N = 131)	Selective Small Public University (N = 342)	Highly Selective Liberal Arts College (N = 100)
Pre-GC1	45, 32, 23	53, 21, 26	53, 21, 26	64, 15, 21
Post-GC1	53, 23, 24	52, 25, 23	50, 25, 25	65, 17, 18
Post-GC2	———	43, 40, 17	———	58, 23, 19
Post-OC2	———	64, 19, 17	———	62, 21, 17
Post-Junior Year	———	77, 11, 12	72, 10, 18	62, 21, 17

year, at which time they began to approach the expectations of chemistry faculty for learning chemistry. Data for the averaged agree–disagree (favorable, unfavorable, and neutral) student responses across all four undergraduate institutions are summarized in Table 2.

Discussion of Cognitive Expectations

Faculty versus Students

One of the more important findings from the MPEX study was to identify a large, statistically significant gap in cognitive expectations between teachers and learners of physics *(13).* To determine whether an analogous gap existed in our sample of chemistry teachers and students, independent samples t-tests were performed. Faculty responses were compared to student responses from three of the four learning institutions sampled—LA, SP, and OP—on each CHEMX cluster at two points in time: pre-general chemistry I and again after completion of the junior year. (CC students were excluded from this analysis as CC offered only general chemistry and organic chemistry.)

With the single exception of the laboratory cluster at LA, an analysis of the results shows that statistically significant differences ($p < 0.05$) exist between the faculty and students at all three institutions at the beginning of general chemistry I. By the end of the junior year, all but two of these differences have disappeared ($p > 0.05$); that is, there is no longer any statistically significant difference between the cognitive expectations of the students and the faculty (see the online Supplemental Material$^{\text{W}}$ for specific t- and p-values). What follows below are several analyses to more closely examine this "closing of the gap" between student and faculty expectations for learning chemistry.

First-Semester General Chemistry

A comparison of the pre-general chemistry I results (Table 2) across the four institutions sampled shows that the percentage of favorable responses rises with the selectivity of the institution. Unlike Redish's MPEX results for first-semester university physics, no significant increases or decreases in cognitive expectations were detected with the CHEMX survey by the end of the first semester of general chemistry, as indicated by paired-samples t-tests. These results indicate that chemistry faculty make little progress in changing their students' cognitive expectations about learning chemistry during the students' initial experience with college chemistry. This finding stands in contrast to the significant decreases in cognitive expectations during first-semester physics in the MPEX *(13).* However, 15 weeks is a relatively short period of time to promote change in how students think about learning; the CHEMX findings are consistent with Perry's work on cognitive development *(14–16).*

Second-Semester General Chemistry

One interesting trend suggested by the student data is the decline in expectations that occurs by the end of the second semester of general chemistry, as seen by comparing post-GC1 scores to post-GC2 scores in Figure 2 and Table 2. Although paired-samples t-tests do not meet the threshold for statistical significance of $p < 0.05$, the more sensitive power analysis recently described by Lewis and Lewis *(24)* does indicate that the measured declines of cognitive expectations occurring in the second semester of general chemistry are not due to chance.

In order to further explore whether the means for post-GC1 and post-GC2 were statistically indistinguishable as suggested by the t-test, we performed a power analysis, recently published by Lewis and Lewis *(24)* as important to rule out the possibility of type II error (i.e., the likelihood that the means are in fact different, but the t-test is not powerful enough to detect this difference). Lewis and Lewis wrote "Power analysis estimates the power of a statistical test, which is the probability that a test will correctly lead to the rejection of the null hypothesis" (*24,* p 1408). The null hypothesis in our case is that the means for post-GC1 and post-GC2 are equivalent, with the alternative hypothesis being that they are in fact, different from one another. By means of the calculations outlined in Lewis and Lewis's paper, the power of the t-test we used to determine whether the means for post-GC1 and post-GC2 are different can be estimated to be 42%

for LA and 9% for OP. That is to say, there is a 42% chance that the two means were equivalent at LA, and a 58% chance that the means are different, but the *t*-test was unable to detect the difference. This is most likely due to small sample size ($N = 46$). Likewise, the power of 9% at OP suggests a 9% chance that the two means are equivalent, with a 91% chance that they are not equivalent, but the *t*-test was limited in its power to detect this difference. Lewis and Lewis cite 20% as the standard limit for establishing reasonability of the probability of a type II error being present (*24,* reference 10 therein).

CHEMX cannot identify any particular cluster (e.g., laboratory or math link), as symptomatic of the decline because data analysis reveals a similar decline in expectations across most of the individual clusters as well. What is happening during general chemistry II to cause a decline in students' expectations about learning is an area of research beyond the scope of this study; possible hypotheses are discussed below.

Organic Chemistry and Beyond

After general chemistry II, Figure 2 and Table 2 show that students' scores increase; that is, their expectations begin to improve. By the end of junior year, students at OP and SP have surpassed their initial, pre-general chemistry I levels. LA students have improved slightly since general chemistry II, but have not improved upon their pre-general chemistry I expectations. Analysis of variance (ANOVA) tests were conducted to determine whether any of the overall changes within each university were significant. The ANOVA results show that the changes that occurred at the SP were significant ($F = 3.872$, $p = 0.005$) while those at the LA ($F = 0.964$, $p = 0.431$) and OP ($F = 0.301$, $p = 0.825$) were not. (N.B.: the latter is due to the small sample size of junior chemistry majors.)

What cannot be fully ascertained from these quantitative data are the reasons underlying an increase in expectations. Do expectations increase because students begin to cognitively mature, perhaps to think more like professional chemists; or, do expectations improve because struggling students are "weeded out" by the end of the sophomore year?

Chemistry Majors versus Nonchemistry Majors

Although the data reported in Table 2 show no significant change in student expectations at the liberal arts college between pre-general chemistry I and the end of organic chemistry, we used demographic information (e.g., gender, major) as a covariant to examine whether any changes occurred for particular subgroups. An agree–disagree plot was generated that separated students at LA into chemistry–biochemistry majors and nonchemistry majors (Figure 3). This analysis revealed substantial differences in how students' cognitive expectations change over time.

Figure 3 shows that the cognitive expectations of chemistry–biochemistry majors steadily improve over the first two years of chemistry instruction, while nonchemistry majors experience prolonged declines. Curiously, nonmajors begin their study of general chemistry with higher expectations than chemistry–biochemistry majors; that is, students with no intention of majoring in chemistry actually have views about learning chemistry that more closely resemble those of chemistry faculty at the beginning of general chemistry. Yet, paradoxically, these students' assessment of what learning chemistry requires of them declines as they study more chemistry; their views digress from those of the faculty. Simultaneously, students who declare an interest in majoring in chemistry–biochemistry begin their studies with views about learning chemistry far removed from those of their faculty. And yet, they persist in their major, moving toward the views of the faculty over the first two years of chemistry study.

Figure 3. Agree–disagree plot of LA chemistry–biochemistry majors vs nonchemistry majors, overall results. The solid black arrow indicates the overall trend for chemistry–biochemistry majors, while the dashed arrow indicates the overall trend for nonchemistry majors.

Conclusions

Ausubel and Novak have articulated the important role that prior knowledge plays in student learning, both prior knowledge about concepts and about how to learn. Extensive research has explored student understandings and misconceptions. This research makes a significant contribution to exploring the second dimension of prior knowledge—learning about learning. We have adapted previous research in physics education to develop a reliable and valid instrument called CHEMX to measure students' knowledge about what they will be expected to do to learn chemistry, namely, their cognitive expectations for learning chemistry. CHEMX can detect gaps between faculty expectations for learning and those of students, as well as measure changes in students' cognitive expectations across the chemistry curriculum, as well as across a diverse group of institutions.

Research shows that students enter general chemistry I with expectations that differ significantly from those of their faculty. Student expectations change very little during general chemistry I but undergo a period of decline during the second semester of general chemistry. Students reverse this trend during the sophomore and junior years. Expectations for learning chemistry differ between chemistry–biochemistry majors and nonchemistry majors.

Future Research

CHEMX provides an easy-to-use tool for chemists to "take the cognitive temperature" of their students. Additional research is necessary to explore the trends presented here. Of particular note is the decrease in cognitive expectations that occurs during the second semester of general chemistry. What factors contribute to such a decrease? One possible hypothesis stems from the nature of the curriculum in the typical general chemistry II course, which tends to be mathematically driven and emphasizes repetitive calculation (e.g., K_c, K_f, K_{sp}, K_p, K_a, etc.). In such a heavily mathematical environment, it can become easy for students to focus exclusively on the equations and algorithmic strategies *(25–27)* and to lose sight of learning the underlying chemical concepts.

The observed decline in cognitive expectations is also consistent with multiple theories describing the cognitive development that students undergo during this time. According to Piaget, learners will make the effort to reorganize their schema for learning only when such schema no longer sufficiently function *(28, 29).* Perry's theory of intellectual and ethical development also recognizes periods of intellectual retreat or escape that can accompany cognitive development *(14).* All intellectual growth, therefore, is accompanied by a period of disequilibrium in which an imbalance exists within the learner's mind. Our research group refers to this disequilibrium as the struggle to connect what they know, to what they need to know, to what they know about learning *(5).* An in-depth study of this crucial period will be required to better understand the observed decline. More importantly, such research should lead to a better understanding of the students' cognitive processes and might also identify mechanisms to help students bridge this gap.

CHEMX should be tested with larger groups of students across multiple institutions to further explore the differences discovered between cognitive expectations of chemistry majors and nonchemistry majors. CHEMX should also be tested in multiple environments in which chemists are innovating with new curricula and pedagogies. We invite chemists to use CHEMX[1] in their classrooms and labs to measure differences between students in their typical environments and the host of innovations that characterize chemistry education today.

Note

1. An online database for CHEMX can be found at *http://www.chemx.org* (accessed May 2007). Faculty may register their courses for students to respond through this site, as well as view automated data analysis of class results.

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WSupplemental Material

A discussion regarding the power analyses mentioned in the paper, an additional data table, and the CHEMX instrument are available in this issue of *JCE Online*.

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