CHEMX: ASSESSING COGNITIVE EXPECTATIONS FOR LEARNING CHEMISTRY

by

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Abstract

The heart of teaching and learning chemistry is the ability of the teacher to provide experiences that share a conceptually abstract, mathematically-rich subject with novice learners. This includes not only chemistry concepts, but also knowledge about how to learn chemistry. The cognitive expectations that students possess for learning chemistry in the university classroom impact their success in doing so.

Physics education research has explored the idea of student expectations with regards to learning physics, resulting in the development of the MPEX (Maryland Physics Expectations) Survey. Unfortunately, up until this point chemists have not had the means of measuring the cognitive expectations that students have for learning chemistry – this has changed with the creation of CHEMX (the Chemistry Expectations Survey). The present study details the development of the CHEMX Survey and how it was used to measure the change in cognitive expectations that students experience as they proceed through the courses required of a typical undergraduate chemistry degree. Results show students' cognitive expectations only slightly change during the first semester of general chemistry before sharply declining during the second. This downward trend is reversed during the sophomore and junior year.

Acknowledgments

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Chapter 1. Statement of the Problem

During the last 30 years, chemistry education researchers have described, diagnosed, and treated many problems that students have in learning chemistry. As a result, new methods for teaching chemistry have been developed and new paradigms for student learning have been proposed; however, despite tremendous efforts, little progress has been made.[1] Students continue to struggle with the subject, and the myth that chemistry is impossible to learn is legend among students. Studies from across the globe have reported that students experience high levels of chemophobia, i.e., a fear of chemistry and chemicals in general.[2-4] This has generally resulted in lower student enrollments and a higher percentage of students earning D's, F's, or completely withdrawing from chemistry courses; in some cases, this can reach as high as 30%.[5] In the words of Alex H. Johnstone: "Internationally something went wrong with chemistry teaching, and students voted (and still do) with their feet to avoid chemistry."[6]

In the face of student attitudes like those described above, chemists must seriously examine how chemistry is experienced by novice learners. Specifically, what is it about chemistry that students find so difficult? Many have dismissed this question by saying that students are lazy and do not spend the needed time nor expend the effort required to succeed. Though this is certainly the case in some instances, many counterexamples exist – students that spend an inordinate amount of time and effort trying to succeed but never truly do.

Researchers in the physics education community have pointed to the importance that expectations play in the ultimate success or failure that students achieve in any particular course.[7] These expectations help shape the attitudes that students bring with them into the classroom and help students decide such things as how frequently to attend class, how much time and effort to spend working on assignments, and even what to listen to during class.[7]

Despite the crucial role that expectations play in determining student success, such expectations remain an understudied area in chemistry education. It is the purpose of this research, therefore, to describe the development of a quantitative measure of students' expectations for learning in the chemistry classroom. This research will also explore how such expectations change as students proceed through the chemistry courses required of an American Chemical Society (ACS) approved undergraduate chemistry degree.

Chapter 2. Literature Review

In order to conduct chemistry education research, it is important to have a firm understanding of the theories surrounding student learning and factors that influence a student's success in chemistry. This chapter reviews the literature relevant to the current research study.

The Role of Prior Knowledge

At the beginning of *Educational Psychology: a Cognitive View,* author David Ausubel writes: "If I had to reduce all of educational psychology to one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.[8]" This seemingly simple axiom is a powerful idea in educational theory today as it has served as the catalyst for change – both in the way that students are taught and in how it is believed that they learn. Ausubel further stipulates that **meaningful learning** occurs when students purposefully make connections between new information and that which has already been learned.[8] Extending and expanding upon these ideas to make them more applicable for the science classroom, Joseph Novak added additional requirements that new information incorporate elements of the cognitive, affective, and psychomotor domains; that is, new information must incorporate elements of thinking, feeling, and doing.[9]

Novak's theory of education, now known as human constructivism, likens the learning process to the construction of a home.[9] It would be foolhardy to attempt to build the first or second story of a home without first having a firm and solid foundation upon which to place it. Once the appropriate support mechanisms are in place, additional connections can be made between floor, wall, and ceiling to provide even more strength and stability to the structure. Likewise, new knowledge must be supported by a firm and solid foundation of prior knowledge and for meaningful learning to occur, connections must be made between the old and new.[9]

Meaningful learning requires that the new information interacts in some way with the old. Figure 1 illustrates the information processing theory, the hypothesized mechanism by which meaningful learning occurs.[9, 10] Events, observations, and instructions represent stimuli from the environment around us, such as sights, sounds, smells, tastes, and tactile sensations. During every moment of the day, the human body is bombarded by countless stimuli and, therefore, must depend upon a filtering system to help determine which stimuli should be perceived, i.e., what information should be paid attention to versus what information can be ignored.

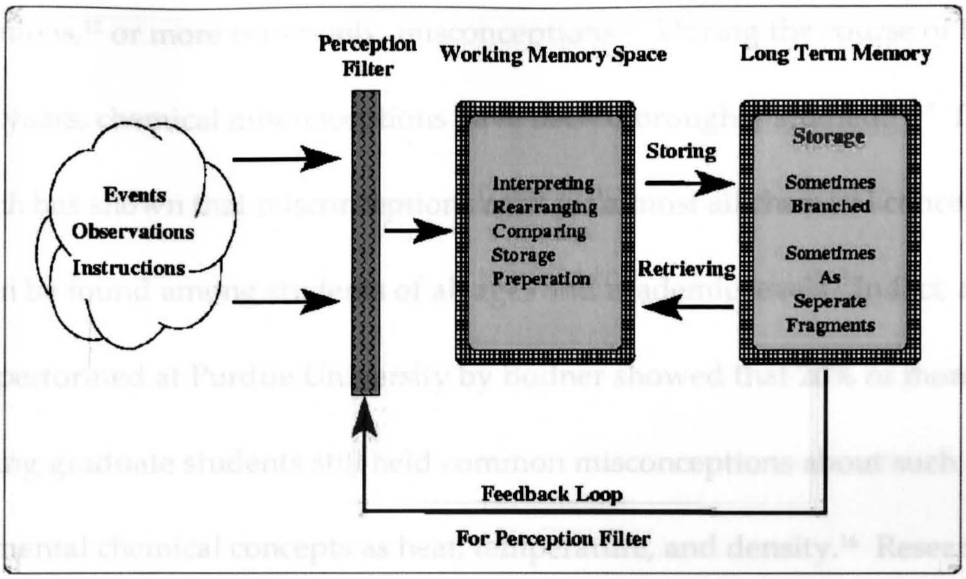


Figure 1. Information processing model.[10]

This filtering system relies heavily upon the information that is stored in the long-term memory – in other words, prior knowledge. Once the stimulus is attended to, it then passes into the working memory, which is a temporary, short-term storage facility. It is here in the working memory that interaction between the new stimulus and prior knowledge can occur. If and when connections are made, the new information can eventually be incorporated into the long-term memory.[10]

The learning process is not perfect, and prior knowledge can become more of a hindrance than a help. Since students build their own understanding and make their own connections, it is possible that in some instances, understanding can differ from accepted standards as defined by the scientific community as a whole.[11] These misunderstandings are frequently referred to as alternate conceptions,[12] or more commonly, misconceptions.[13] During the course of the last 15 years, chemical misconceptions have been thoroughly studied.[11-17] This research has shown that misconceptions exist for almost all chemical concepts and can be found among students of all ages and academic levels. In fact, a study performed at Purdue University by Bodner showed that 20% or more of incoming graduate students still held common misconceptions about such fundamental chemical concepts as heat, temperature, and density.[16] Research has also shown that misconceptions can have surprising sources.[17] For example, one of the most prevalent misconceptions about bonding is that the process of bond cleavage is exothermic. A study of approximately 600 students at McGill University in Montreal showed that nearly 80% of those surveyed felt that bond breakage was the source of energy release in a simple combustion reaction. When the source of this misconception was investigated, students revealed that this particular view of chemical bonding originated primarily in high school and university level biology courses. More surprisingly, however, were the 40% who indicated that they also encountered this misconception in high school and university level chemistry.[17]

Although this work does not investigate student misconceptions, it does focus upon the intellectual and attitudinal development that students experience during the college years. Since misconceptions can interfere with this development, it is important to understand their sources and prevalence in all areas of chemistry.

Intellectual and Ethical Development: The Work of Perry

The understanding of human development has grown greatly over the course of the last 75 years. Just as bodies mature, so too do minds. Due to the work of psychologists like Jean Piaget and Erik Erikson, cognitive, intellectual, and ethical development is now understood to occur in stages.

The college years are a period of intense intellectual and ethical maturation. In order to better understand these maturation processes, William Perry began his study of male students at Harvard and Radcliffe in the 1950's and 1960's. From this research emerged the Perry Scheme (See Figure 2) which contains nine positions – each representing a unique way for students to think about the world around them.[18]

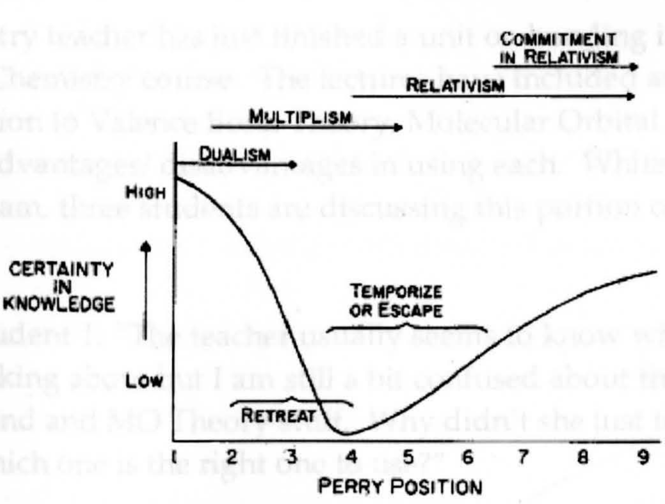


Figure 2. The Perry Scheme of Intellectual and Ethical Development.[19]

These nine positions can be further grouped into four broad categories: Dualism, Multiplism, Relativism, and Commitment to Relativism.[18] As is the case with most developmental theories, as learners move sequentially from one stage to the next, they develop a more sophisticated way of viewing the world; however, the Perry Scheme is unique in that it provides three mechanisms by which intellectual development can be interrupted (listed as "retreat," "temporize," and "escape" in Figure 2). These processes typically occur as students transition from one stage to the next – retreat during the transition from Dualism to Multiplism and temporizing and escape as students move from Multiplism to Relativism. Each of these interruptions may only be temporary regressions or life-long commitments.

To chemists, the relevance of the Perry Scheme may not be immediately apparent; yet consider the following scenario:[19]

> A chemistry teacher has just finished a unit on bonding in her General Chemistry course. The lectures have included an introduction to Valence Bond Theory, Molecular Orbital Theory, and the advantages/ disadvantages in using each. While studying for the exam, three students are discussing this portion of their notes.
>
>> Student 1: "The teacher usually seems to know what she is talking about but I am still a bit confused about this Valence Bond and MO Theory stuff. Why didn't she just tell us which one is the right one to use?"
>>
>> Student 2: "I also was a bit confused by that part. Although it looks like both theories work, she seemed to talk more

> about the Valence Bond approach so that is the one I am going to use on the exam."
>
> Student 3: "I thought that was a great lecture! It is so interesting to see how scientists can have two competing theories for the same thing and how one theory seems to better explain certain aspects of a model. It all depends on what you are trying to explain."

Although all three students were present for the same lecture, it is interesting to see how each can perceive the information in such radically different ways. The first student clearly shows signs of what Perry refers to as Dualistic thinking – a stage of intellectual development that is characterized by the learner looking at things in one of two ways. In this example, the student is trying to categorize the two theories as being either right or wrong. Student 2 exhibits characteristics of a Multiplistic thinker, i.e., he recognizes that there are two theories and that they both seem to work. The problem is that the student is still trying to figure out which one is better to use and only settles on Valence Bond Theory because the teacher seems to favor it. Student 3 responds in a manner that shows a level of intellectual maturity not present in the previous two students. He understands that there are times when scientists can have more than one right answer, and as a consequence, there can exist two or more theories, all trying to explain the same phenomenon.

Teachers must be aware of the intellectual development of their students. Though it is important that they challenge students to grow and mature, there exists a fine line between challenge and impossibility. Studies have shown that the average freshman enters college at about 2.4 on the Perry Scheme.[20] By the time the average student graduates four years later, he is now at 3.2.[20] In other words, students tend to enter college in the Dualist phase and emerge four (or more) years later as Multiplistic thinkers. This research has also shown that the best way to encourage student growth is to challenge them with a +1 position, that is, if the student is a dualist thinker, the most growth occurs when they are challenged by a multiplistic argument.[21]

The Structure of Chemistry Knowledge

Why is science difficult for students to learn? This question was the subject of an article written in 1991 by Alex H. Johnstone. Though the issue is a complex one, he made the following three hypotheses: (1) problems can arise in the transmission system – the methods the instructor uses to convey the message and the facilities and the available resources; (2) problems may exist within the receivers (the learners) themselves; and (3) there could be inherent flaws within the nature of the message itself.[22] In the majority of cases, he concludes, it is a combination of all three factors.

This combination effect is best demonstrated by what Johnstone calls "multilevel thought." All chemistry knowledge can be divided into one of three domains and represented as shown in Figure 3.[22]

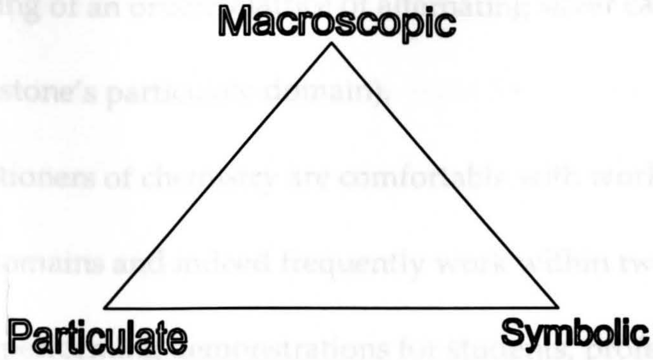


Figure 3. Johnstone's triangle depicting the three domains of chemistry knowledge.[22]

The following scenario illustrates this separation of knowledge:

A chemistry professor discussing precipitation reactions writes the following reaction on the board:

$$AgNO_3\ (aq) + NaCl\ (aq) \rightarrow AgCl\ (s) + NaNO_3\ (aq)$$

The professor then proceeds to perform a demonstration for his students by mixing a clear solution of silver nitrate with an equal volume of a clear, sodium chloride solution. A white precipitate, silver chloride, is produced.

The letters, numbers, and symbols used to write the chemical reaction (Johnstone's symbolic domain) are related to the clear, silver nitrate solution and the clear, sodium chloride solution that reacts to form the white precipitate (Johnstone's macroscopic domain). This newly formed precipitate exists as a solid consisting of an ordered lattice of alternating silver cations and chlorine anions (Johnstone's particulate domain).

Practitioners of chemistry are comfortable with working within any of these three domains and indeed frequently work within two or three at the same time. When performing demonstrations for students, professionals are able to immediately reconcile what they observe with what they know is occurring at the atomic or molecular level. In addition they are able to represent the process that is occurring with letters, numbers, and equations. The problems arise when they ask students to do the same.

Though they may be able to discern what is occurring at the macroscopic level, students have great difficulties connecting this with the particulate and the symbolic domains. Professional chemists may not remember what it was like when they were novice learners of chemistry and subsequently assume that students are making the same connections in their minds that the professionals are making in theirs. In all likelihood, students are not.[22]

The connections among these three domains emphasize the importance of visualization to learning chemistry. Students will be required to envision atoms and molecules in their minds, and more importantly, be able to flip, rotate, and convert these mental representations from one form to another in order to learn chemistry. Without these essential skills, how can learners of chemistry ever hope to make the necessary connections among the three domains of chemistry knowledge? It is also among these connections that an appreciation develops for the opportunities afforded in having students perform laboratory work. The laboratory is where students are actively engaged; they can most easily begin to connect what they see and do with the chemical symbols used to represent the process they are investigating and the mental representations that they have constructed to embody it.

Attracting Students to Science: *They're Not Dumb, They're Different*

In 1990, a report given to the American Association for the Advancement of Science (AAAS) predicted an alarming trend in the sciences: by the year 2005, there would be an estimated shortfall of anywhere between 250,000 to 700,000 BS and BA recipients in science and engineering.[23] In light of such projected deficits, Sheila Tobias concluded in her report *They're Not Dumb, They're Different: Stalking the Second Tier*[24] that one way to compensate for this shortfall was to actively recruit more students to the sciences. She surmised that it was important, therefore, to look beyond the "usual suspects" who might study science to students in what she termed the *second-tier*: students who are capable of learning and even excelling at science, yet ultimately decide to pursue different career paths. To attract these students, it would be necessary to understand what it is about science that turns away many otherwise bright and motivated students.

To explore these issues, Tobias turned to seven second-tier stand-ins – a fifth-year senior majoring in anthropology; five graduate students in English literature, philosophy, and anthropology; and a college professor of classics. Most of these had taken several advanced science and mathematics courses in high school and for the most part had greatly enjoyed them; however, when it came time to choose a major in college, they had all avoided the sciences for one reason or another. It was their job in Tobias' study to seriously audit an introductory chemistry or physics course and to then comment on what they believed made science difficult to learn for a typical second-tier student.

By and large, these second-tier stand-ins all pointed to the same things when it came time to talk about their experiences in the introductory chemistry and physics courses they had audited. First, most believed that there was too little communication between teacher and student as well as among the students themselves. These auditors craved more interaction with their teachers and fellow students and were turned off by having to sit passively day after day listening to the teacher lecture. They also found the almost exclusive focus on problem solving troubling – they wanted more of the "why" and less of the "how." As one put it:

> I would much rather be asked to attend a formal, inspirational lecture once every week or two and spend the rest of my time with a TA or Macintosh [computer] solving sample problems. There would be at least some degree of interaction with a machine. We

> spend too much time gaining technical knowledge of chemistry, necessary to be sure, but there is formal and even informal information which could be presented to us without numbers and details whereby we might learn what chemistry is doing on the cutting edge, what are its various subfields, and more of its history (p 47).[24]

These stand-ins were also continually confounded by the apparent lack of direction with which the teacher proceeded. One commented that it seemed as if the teacher "pulled topics out of a hat" when deciding what to cover next. Most did finally realize late in the course that there had been a reason for why the topics were covered in the sequence that they were, but that it would have been immensely helpful to know this upfront, to have some general sense of why they were covering what they were and how it was going to relate what they would be doing in the future. In the most basic sense, these students felt as if they had no place within science and that science had no use for the unique skills that they possessed.

Unfortunately, chemists have yet to adequately address the concerns of these students. Not that most chemists are apathetic regarding the situation, but rather because they have no way of measuring where such students stand in relation to their first-tier peers with whom chemists are much more familiar. The current research will attempt to remedy this and provide such a measure.

MPEX and Expectations for Learning University Physics

In 1998, an article appeared in the *American Journal of Physics* describing the development of the Maryland Physics Expectations (MPEX) Survey. Originally developed by Redish, Saul, and Steinberg, the MPEX Survey sought to quantify the cognitive expectations that students have for learning university physics.

The term "cognitive expectations" encompasses a diverse and wide-ranging set of ideas about the process of learning science and the structure of science knowledge itself.[7] What set of skills will be required for students to succeed in science? What activities will they be required to do both in class and out? How much time and effort will be required? The answers to these questions help students to decide how to approach the course and their overall attitudes toward it. When large gaps exist between what students think science *should* look like and what it actually does, problems can ensue. Students may intentionally begin to filter out what the professor is saying or may stop doing assigned readings or other coursework. In fact, they may stop coming to class altogether.[7] It is imperative, then, that scientists have a valid and reliable instrument to measure the expectations that students have for learning so as to discuss the existence of gaps in expectations with their students. It was with this goal in mind that the MPEX Survey was originally created. MPEX consists of 34 questions divided into six clusters[7]:

1. ***Independence***: beliefs about learning physics.

2. ***Coherence***: beliefs about the structure of physics knowledge.

3. ***Concepts***: beliefs about the content of physics knowledge.

4. ***Reality Link***: beliefs about the connection between physics and reality.

5. ***Math Link***: beliefs about the role of mathematics in learning physics.

6. ***Effort***: beliefs about the kind of activities and work necessary to make sense out of physics.

MPEX was administered twice in one semester to more than 1500 students who were enrolled in introductory, calculus-based physics courses at six different colleges and universities from across the nation. The pre- and post-semester results from three of the six universities are presented in Figure 4. Initially, the students surveyed at these universities held significantly lower expectations than their instructors. Surprisingly, over the course of a semester of instruction, this gap widened further. Redish's work raises many additional questions. Why does the gap widen between teacher and student during the course of a semester? What happens to cognitive expectations during subsequent semesters of instruction? What is the situation with regards to cognitive expectations in the other sciences? The desire to find answers to these questions served as impetus for the current study.

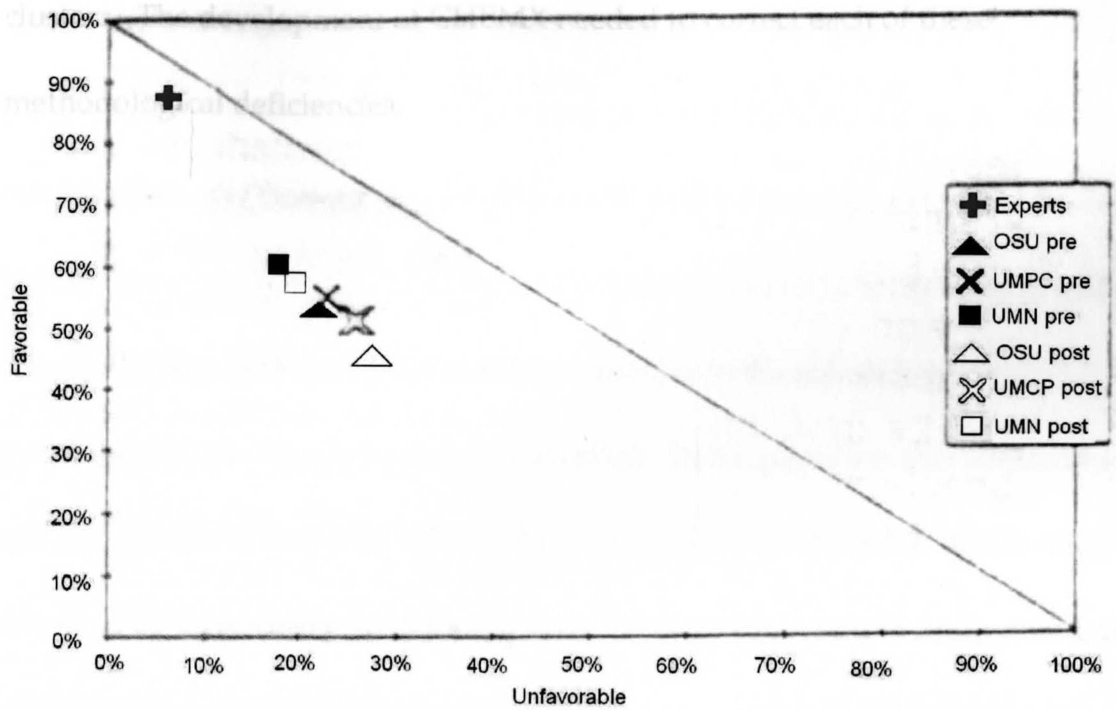


Figure 4. Agree/Disagree Plot of the pre and post-semester MPEX scores[7] [OSU = Ohio State University, UMCP = University of Maryland College Park, UMN = University of Minnesota].

Problems with MPEX

Publication of MPEX came with claims of both validity and reliability. However, a close examination of the original dissertation[25] describing the development of MPEX revealed four methodological flaws: (1) four MPEX statements were included in more than one cluster, (2) eight MPEX statements were not included in any preexisting clusters, (3) the reliability analysis showed that each cluster, as well as the survey overall, was unreliable, and (4) reliability and factor analysis data obtained did not support the existence of six distinct clusters. The development of CHEMX needed to correct each of these methodological deficiencies.

Chapter 3. Methodology

The Nature of Human Subject Research

Research with human beings requires that all participants grant informed consent, meaning that subjects be given sufficient information about the research procedures, research purposes, and any potential risks or benefits so as to make a knowledgeable decision about their participation in the research study – participation that cannot be forced or coerced. Participants are also entitled to ask any questions they may have and to withdraw from the study at any point. Issues of confidentiality and/or anonymity in reporting research findings are also addressed in granting informed consent.

All phases of this research involving human subjects were reviewed and approved by the Human Subjects Research Committee of Youngstown State University (HSRC Protocol Nos. 05-2005, 99-2004, and 85-2003). Copies of all approvals can be found in Appendix A.

Reliability and Validity

One of the most commonly used methods in quantitative chemistry education research is the survey. This versatile instrument allows researchers to sample large subject groups while generally avoiding the high costs and restrictive time constraints of other research methods. Despite their seemingly simple construction, however, the creation of a reliable and valid survey is no easy undertaking.

The reliability of an instrument refers to the consistency of the scores obtained.[26] In other words, if an instrument is reliable, a respondent should score similarly if the instrument is administered on more than one occasion. A commonly used statistical method of testing the reliability of an instrument is the Cronbach alpha. Though it is not the only method available to test reliability, the Cronbach alpha can be calculated if the number of survey items, the mean score, and the standard deviation are known – all quantities that can be gleaned from a single survey administration. The Cronbach alpha can range from 0.00 to 1.00 with values closer to 1.00 indicating a more reliable instrument; however, by convention, the value must be 0.7 or greater for an instrument to be considered reliable.[26]

Establishing an instrument's validity is a more complex issue but at its heart lies the question, "Does the instrument measure what it claims?" To answer this question, one must look beyond statistics since a quantitative means for measuring validity does not yet exist. In the present study, interviews conducted with both faculty and students who completed the CHEMX Survey, along with the survey results themselves, were used to establish the validity of the instrument.

Development of CHEMX

The creation of any survey requires several iterations before achieving a reliable and valid measure. The development of CHEMX began in summer 2003 as part of the National Science Foundation's REU (Research Experience for Undergraduates) Program. This program provides universities across the country the opportunity to bring outstanding undergraduates to their campuses to conduct research for 12 weeks during the summer.

Because of the inherent time constraints of the REU program, the first iteration of CHEMX was only slightly different from the original MPEX. In most cases, the words "physics" and "physical" were replaced with "chemistry" and "chemical." Since most of the students surveyed were enrolled in General Chemistry, most of the math link statements that dealt with derivations and proofs of equations – skills not commonly encountered in lower level chemistry courses – were removed. Using Johnstone's triangle as a guide, five original statements were also added that explored the connections among the macroscopic, particulate, and symbolic domains.

Initial surveying of chemistry faculty and General Chemistry students yielded results analogous to those in physics, namely a statistically significant difference ($p<0.001$) between the expectations of faculty for their students and the expectations that students themselves have. The opportunity to further develop

CHEMX presented itself when this researcher began graduate studies at Youngstown State University in January 2004, with emphasis on the creation of two new clusters of questions: the first, to explore the role that the laboratory plays in learning chemistry; the second, to look at the role of visualization. In addition, the focus of the project expanded to study how cognitive expectations change over the course of a student's undergraduate chemistry education.

The Laboratory Cluster

The laboratory experience is an integral component to learning in the science classroom.[27-30] The original MPEX did not contain any statements probing this dimension of student learning, so ten original statements were created for this cluster.

Do students focus on trying to find the "right" answer in the shortest amount of time possible or do they try to understand the chemical concepts behind the lab that they are performing? Items 1, 16, 28, 39, 48, and 53 are all variations on this theme.

Item 1.	I can do well in the chemistry laboratory (C grade or better) without understanding the chemical principles behind the labs.
Item 16.	It really doesn't matter how hard I work in the laboratory; the most important thing is to get the right answer.
Item 28.	I really don't expect to understand how laboratory instruments work – they are just tools that help me complete the lab.
Item 39.	It is important that I finish a lab as quickly as possible – I'll figure out what the data mean later.

Item 48.	When doing lab calculations, I attempt to work through them myself before looking for help from the lab manual or instructor.
Item 53.	When I do an experiment in the laboratory, it is not important to understand what is happening. I should just follow the directions carefully.

Statements 17 and 32 probe to see what students believe is the purpose of working in the laboratory.

Item 17.	One of the most important things I learn from the laboratory experience is proper laboratory techniques.
Item 32.	The purpose of laboratory is to verify the concepts and principles I learned in lecture.

The last two laboratory statements, items 8 and 55, examine the connections between the lab and lecture and between lab from week to week.

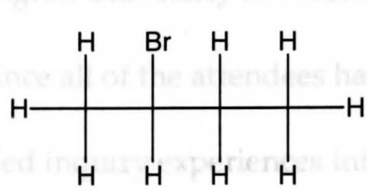
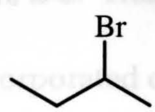
Item 8.	In order to understand lab, I must connect it to what I learn in lecture.
Item 55.	I don't expect to use what I learn during one lab experiment in another experiment.

The Visualization Cluster

The ability to envision atoms and molecules in one's mind is a vital skill necessary in many chemistry courses.[31-33] Students are expected to be able to manipulate atoms and molecules, i.e., be able to flip, rotate, and convert them from one form to the next. "Visualization" is a general term that refers to the combination of separate skills that Fennema and Leder have identified as spatial visualization and spatial orientation.[34] Spatial visualization involves the mental manipulation of all or part of an object. For example, students enrolled in inorganic chemistry courses frequently are required to rotate molecules in their minds when assigning a point group Survey items 5, 18, 23, and 40 explore this dimension of visualization.

Item 5.	When I see a drawing of a molecule in my textbook, I try to imagine what it might look like in 3-D.
Item 18.	It is not necessary for me to be able to rotate atoms or molecules in my head because I can build models if I need to.
Item 23.	I don't spend much time constructing 3-D models of the 2-D structures that I draw in my class notes or read in my textbook.
Item 40.	Being able to visualize molecules in 3-D is an important skill for learning chemistry.

Spatial orientation refers to the ability of a person to understand a visual representation or comprehend some change that has taken place between two representations. This includes the ability to represent an atom or molecule in more than one manner. For example, 2 – bromobutane can be represented by any of the following:

C_4H_9Br $CH_3CHBrCH_2CH_3$  

Clearly, the ability to recognize that all of the above formulas represent the same molecule is important for learning chemistry. Therefore, survey item 29 was created.

Item 29. Solving a chemistry problem may require me to be able to draw molecules in more than one way.

The visualization cluster also explores the domains of chemistry and the connections between them as described by Johnstone in items 25 and 33.

Item 25. When I do an experiment in the laboratory, I try to picture the chemistry that is happening in terms of atoms and molecules.

Item 33. After I have watched a chemistry demonstration, I should be able to explain what I saw in terms of the reactions of atoms and molecules.

CHEMX Pilot - Testing

After creating the laboratory and visualization clusters, CHEMX was pilot-tested in order to identify any potential problems with the instrument, particularly with regard to the original statements that were added.

Pilot-testing took place on June 7 and 8, 2004, at the 10th annual Middle Atlantic Discovery Chemistry Project (MADCP) meeting held at the Mount Vernon campus of the George Washington University in Washington, DC. This venue was particularly appropriate since all of the attendees had incorporated or were interested in incorporating guided inquiry experiences into their chemistry classes, which closely approximated the testing conditions used in the MPEX study. Approximately 50 surveys were distributed – 31 were returned. In addition to answering the survey items, several open-ended questions asked respondents to comment on any statements that they believed were awkwardly worded and solicited their overall impression of the survey. The pilot – testing results were quite encouraging with a Cronbach alpha value of 0.9136. This value is similar to those of many commercially available achievement tests.

Most respondents offered comments indicating that the items' wording was fine and that there were no ambiguous statements. Additional critical comments focused upon three survey items: 17, 36, and 47. These comments were supported by concerns in the reliability analysis as these three items showed either little or negative correlation to other items in the survey.

Item 17. One of the most important things I learn from the laboratory experience is proper laboratory techniques.

Respondents were concerned that students who read this statement might believe "that there can't be more than one 'the most'" when in reality there can be. In order to remove any potential confusion, item 17 was rewritten:

Item 17. It is important that I learn proper laboratory techniques in this course.

With regard to item 36,

Item 36. Chemistry is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.

one concern was that it was "not clear to me what 'it' refers to in the final clause." Another commented that "the first half sounds like something one might agree with, while the second half one might disagree with (hopefully)." To help eliminate these ambiguities, the item was rephrased as:

> **Item 36.** It is necessary for me to have to relate chemistry to the real world.

Lastly, there were significant problems with statement 47:

> **Item 47.** A significant problem in this course is being able to memorize all the information I need to know.

This statement showed a negative correlation to other statements in the survey, as well as elicited comments about its structure from several respondents. Similar to the comments made on item 36, respondents felt that "I sort of agree with one half and not with the other half…" while another commented that he/she was "unsure what 'significant problem' means." Further consideration of this statement showed that respondents could really be responding to two different things – being <u>able to</u> commit to memory versus <u>needing</u> to commit to memory. In light of the duplicitous nature of this statement, the negative correlation with the other survey items, and the comments provided, item 47 was deleted.

Faculty Surveying

Though the focus of this project was to ascertain how students' expectations change over the course of their undergraduate academic careers, collecting data from faculty as experts provided an important reference benchmark. A sampling plan was developed to achieve a robust and varied sample of faculty from across the nation. The country was divided into six regions as indicated in Figure 5. From each of the six regions, three states were chosen at random using a random number generator. Using the list of approved chemistry programs provided by the American Chemical Society's Committee on Professional Training[35], three chemistry departments were randomly selected from each of these 18 states, resulting in the selection of 50 chemistry departments.

Figure 5. Map of the United States depicting the six regions utilized for faculty surveying of CHEMX.

Note that both Alaska and Hawaii were randomly chosen and that each only contains one ACS approved program. All current chemistry faculty members in each department (excluding part-time and emeritus) were sent a letter inviting them to participate and requesting that they respond to an online version of CHEMX. In all, 730 letters were sent; 157 faculty responded (22% response rate).

Final Version of CHEMX

Based upon the reliability and factor analysis of the faculty data collected (see Chapter 4 for specific details), additional items were deleted from CHEMX: Items 2, 4, 8, 14, 18, 32, 38, and 41. These eight statements in particular had low or negative correlations to other CHEMX statements and did not fit well in any particular cluster. The remaining 47 items which constituted the final version of CHEMX were analyzed for the existence of clusters. Deletions based upon faculty data resulted in only two statements remaining in the independence cluster and one statement in the coherence cluster. Therefore, the independence and coherence clusters were deleted and the three remaining statements were examined with regard to placement in other clusters. The four statements that had been included in more than one MPEX cluster were placed into a single one based upon the factor analysis: item 12 from math-link and independence to just math-link; item 45 from concepts and independence to just concepts; item 26 from math-link and coherence to just math-link; and item 15 from math-link and effort to just math-link. A copy of the final version of the CHEMX Survey is included in Appendix B. The seven CHEMX clusters which emerged from the data analysis are described below:

1. ***Effort***: beliefs about the kinds of activities and work necessary to make sense out of chemistry.

2. ***Concepts***: beliefs about the content of chemistry knowledge.

3. ***Math Link***: beliefs about the role of mathematics in learning chemistry.

4. ***Reality Link***: beliefs about the connections between chemistry and the real world.

5. ***Outcome***: beliefs about the value of learning chemistry.

6. ***Laboratory***: beliefs about the purpose and value of performing chemistry experiments in the laboratory.

7. ***Visualization***: beliefs about the role of picturing atoms and molecules in learning chemistry.

The items included in each cluster and the response sets associated with each are described in Table 1. The view that was most commonly adopted by teachers and other experienced chemists is designated as "favorable" while the view most commonly held by novice learners is described as "unfavorable." All statements that required recoding for purpose of scoring are indicated by an asterisk (*) after the statement number.

Table 1. Favorable and unfavorable dimensions of the seven CHEMX clusters.

Cluster	Favorable View	Unfavorable View	CHEMX Items
Effort	Makes the effort to use the information available and tries to make sense of it	Does not attempt to use available information effectively	2, 6*, 8, 19*, 22, 31*, 34*, 38*, 41
Concepts	Stresses understanding of the underlying ideas and concepts	Focuses on memorizing and using formulas	4*, 28*, 36, 37*, 43
Math-link	Considers mathematics as a convenient way of representing chemical phenomena	Views chemistry and math as independent with little relationship between them	5*, 9*, 11, 21*, 29*
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	14*, 26, 30*, 35, 42
Outcome	Believes learning chemistry is essential to ultimate career goals	Believes learning chemistry is simply another obstacle to overcome before getting to the "important" material	7, 15, 16*, 17*, 25*, 40, 45*, 47
Laboratory	Stresses the importance of understanding the chemical concepts behind the experiments	Views laboratory experiments simply as steps to follow and data to collect with little relationship between it and what is learned in lecture	1*, 12*, 13, 23*, 32*, 39, 44*, 46*
Visualization	Considers the visualization of atoms and molecules in 3-D as essential to understanding chemistry	Views visualization as a skill unnecessary to learning chemistry	3, 10, 18*, 20, 24, 27, 33

Outcome Cluster

In order to facilitate scoring of the surveys, the five remaining statements that were not placed into a cluster were incorporated into the new outcome cluster. Also placed with this cluster were the three independence and coherence statements remaining after the deletion of their respective clusters. This methodological decision is supported by the factor analysis. The statements in this cluster all probe aspects of a student's expectations for the outcome of instruction. Do students come to view chemistry as a set of knowledge and skills essential for their overall success or is it simply a barrier to cross before learning more important material? Belief in the former requires students to substantially rethink, restructure, and reorganize their ideas about the world around while the latter requires no such effort. Items 7, 15, 16, 17, 25, 40, 45, and 47 are all included in this cluster.

Student Surveying

In order to answer the research problems described earlier, students from a number of different institutions were surveyed at different points in their academic development. In a study of student development, a longitudinal model would allow researchers to follow the same students throughout the course of the study. Because of the time restrictions placed upon this work, such a model was not appropriate as it would have taken at least four years to complete the study. Instead, sampling across different courses was used as a proxy for following individual student growth. Specifically, students were surveyed upon beginning general chemistry, upon completion of each semester of general chemistry, one year of organic chemistry, the junior year, and the senior year. A description of each of the participating educational institutions follows.

- **Small, Selective Public University (SSPU)**: Chemistry courses are typically taught using a traditional lecture model though many do include a strong collaborative learning component. Students enrolled in general chemistry I, instrumental analysis, and inorganic chemistry participated in the research.
- **Selective, Liberal Arts College (SLAC)**: Instruction within the department of chemistry ranges from traditional lecture to the use of POGIL (Process Oriented Guided Inquiry Learning)[35] across several courses. Students enrolled in general chemistry I, general chemistry II, organic chemistry II, and juniors participated in the research.
- **Medium, Open-admission Public University (MOAPU)**: Lecture courses in the department of chemistry are typically taught by faculty while labs and recitations are taught by graduate students. Most instructors utilize a traditional lecture model. Students enrolled in general chemistry I, general chemistry II, organic chemistry II, quantitative analysis, and physical chemistry II were surveyed. Students conducting undergraduate research also participated.

- **Community College (CC)**: The college offers pre-baccalaureate programs for students planning to eventually transfer to a four-year institution. Because of class limitations, only students enrolled in general chemistry I participated in the current research study. The instruction in this general chemistry course utilized POGIL.

Chapter 4. Results

The purpose of this research study was to develop a valid and reliable means of measuring the cognitive expectations that students have for learning chemistry and to then use this instrument to determine how these expectations change over the course of an ACS approved undergraduate degree in chemistry. In so doing, the following research questions were identified:

1. How do the expectations that faculty members have for their students compare across the different disciplines of chemistry?
2. How do student expectations for learning chemistry change as they progress through an ACS approved undergraduate degree in chemistry?
3. How do student expectations for learning chemistry compare to those of their instructors?

Reliability and Validity of CHEMX

One of the goals of this research was to improve the reliability and validity of CHEMX in comparison to MPEX. Table 2 provides a comparison of the Cronbach alpha values of the MPEX Survey clusters versus the clusters of the CHEMX Survey, as calculated from the faculty responses.

Table 2. Cronbach alpha values of MPEX and CHEMX clusters.

Cluster	MPEX	CHEMX
Overall	0.81	0.97
Effort	0.47	0.85
Independence	0.48	---
Concepts	0.49	0.73
Math-Link	0.66	0.82
Reality-Link	0.67	0.86
Coherence	0.49	---
Laboratory	---	0.85
Visualization	---	0.89
Outcome	---	0.73

The values in Table 2 clearly indicate that the reliability of the CHEMX clusters has significantly improved to the point where each cluster is now reliable. In addition, the reliability of the overall survey is quite good with a Cronbach alpha value of 0.97.

In order to assess the validity of CHEMX, interviews were conducted with three chemistry faculty members and six students enrolled in general chemistry II. Both groups had previously completed the survey. A copy of the consent forms and interview guides used for the interviews are included in Appendix C. Subjects were given 14 statements from CHEMX, asked to answer each, and then to explain why they answered the statement accordingly. Using this information, it was concluded that although the respondents may not have answered all of the statements correctly, they were correctly interpreting them.

Excerpts from two faculty interviews for two of these 14 statements are included. The first statement asked the respondent to answer, "Only a few very specially qualified people are capable of really understanding chemistry." The first faculty member, an organic chemist, answered this statement by saying:

> I will say disagree. I disagree because I've seen some students who come into my classes having a very sort of… not a very strong understanding of general chemistry or not a very good feel for what chemistry is about but then through hard work or practice with problems or through office hours or what have you, do come out with what I call an understanding.

The second faculty member, an inorganic chemist, explained his answer this way:

> The first one, only a very few specially qualified people are capable of really understanding chemistry. I put 2, disagree. It shouldn't be, I wouldn't like a student to go into a class thinking I've got to be extra brilliant or I've got to be one of a few specially qualified people to understand it. If they do, if they work hard enough, they're going to have some understanding. Maybe it won't be a thoroughly in-depth understanding of all of the aspects of the course but they should come away with some basic concepts and it should be directly related to the amount of work they put into it and perhaps their attitude towards the learning.

The second statement asked the interviewee to answer the statement, "Solving a chemistry problem may require me to draw atoms and molecules in more than one way." The organic chemist strongly agreed with this statement and explained his answer this way:

> Yes, organic chemistry is three-dimensional as is biology and my sort of take on organic chemistry is that we start out simple but we very quickly get into complex three-dimensional structures. The world is not flat, the world is three-dimensional so they got to be able to see things and turn things around and I spent a lot of time on my practice exams, and then on my real exams… interpret this into this. Let's take a Fischer projection and turn it into a three-dimensional projection so that you can actually see why these… these are shorthand notations to save time, to speed things up but in reality, a molecule is not flat.

The inorganic chemist also agreed with this statement:

> I think that a student should realize that chemistry problems in general, whether you're drawing molecules or doing a calculation, that they should realize that there's more than one way to do it and you should accept that. When you take a test, for example, that question might be worded slightly different than you're used to seeing it…You like students to be open to the concept that…well, sometimes you have to look at the same thing in two different perspectives. I mean, a horse looks very different from the side as opposed to the back or front ends, for example. You're not going to see the whole picture sometimes unless you're willing to admit that you have to look at things from different perspectives.

Factor Analysis

Factor analysis attempts to identify underlying factors that explain the pattern of correlation among a set of items. In this manner, it is possible to organize the individual survey items into clusters. A rotated factor analysis was performed on the instructor data. The component matrix for this process is included in Table 3. For convenience, each CHEMX cluster has been color-coded (lab = pink, concepts = red, math-link = orange, effort = yellow, reality-link =

green, outcome = blue, and visualization = purple). In addition, the largest component correlation for each item has also been color-coded in a similar fashion.

The factor analysis revealed the existence of eight components. All five reality-link items (green) loaded into component one; all seven visualization items (purple) loaded into component two; and four of the five concept items (red) loaded into component five. At this point the factor analysis becomes ambiguous as the statements in the other four proposed clusters load into two, three, or even four different factors; however, considering the high reliability of each cluster as reported in Table 2, the choice of clusters was appropriate. Furthermore, factor analyses performed on the individual CHEMX clusters yielded only one component in each.

Table 3. Factor analysis component matrix.

	Component							
	1	2	3	4	5	6	7	8
rlab1	.351	.367		.457				
rlab12	.478		.377		.396			
rlab23	.301		.528	.402				
rlab32	.544				.368			
Rlab44	.410		.575					
rlab46	.418		.313	.303	.354			
lab13	.513					.328		
lab39	.545					.438		
rcon4				.301	.502	.399		.305
rcon28					.668			
rcon37					.600			
con36					.648			
con43								.720
rmath5			.691					
rmath9	.310	.350		.496				
rmath21		.305	.697					
rmath29	.334			.643				
math11		.344	.599			.324		
reff6	.392			.552		.336		
reff19	.348			.494	.383			
reff31	.492		.426					
reff34	.337	.385	.468					
reff38				.467		.437		
eff2	.364						.594	
eff8	.320					.654		
eff22	.518				.317	.361		
eff41	.430	.403						
rreal14	.516	.353	.339	.366	.302			
rreal30	.657			.346				
real26	.610			.334			.306	
real35	.649						.363	
real42	.725							
rout16					.584			
rout17			.302	.410	.322		.404	
rout25	.553		.300	.381				
rout45				.523			.423	
out7	.378					.625		
out15	.606							
out40	.546				.325			
out47							.437	.557
rvis18		.506	.338				.307	
vis3	.335	.729						
vis10	.432	.666						
vis20	.472	.582						
vis24		.669	.341					
vis27		.606				.324		
vis33		.646						

Faculty Responses

An online version of CHEMX was administered to 157 faculty members from 50 chemistry departments from across the country. 25% of the respondents teach at private institutions and 19% are women. Other demographic information for these faculty members is included in Figures 6 through 8. The numbers in the white boxes in each wedge correspond to the number of respondents in that group.

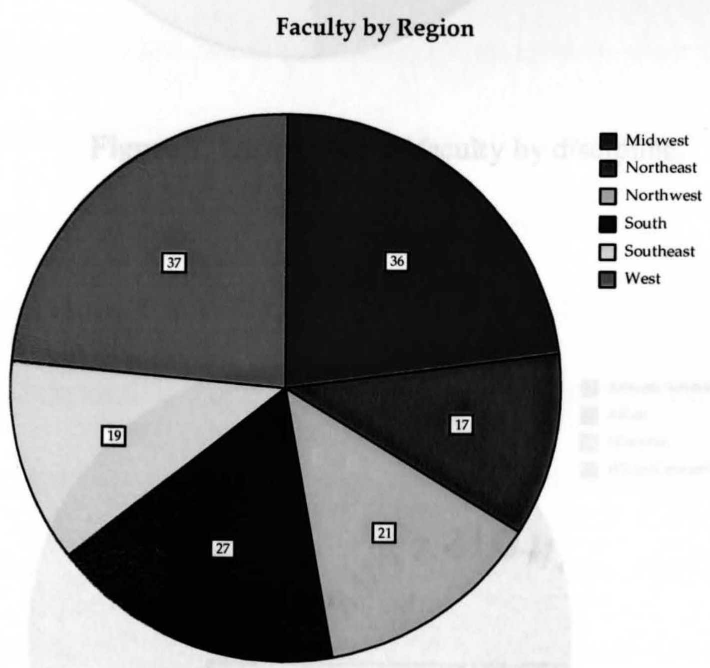


Figure 6. Distribution of faculty by region of the United States.

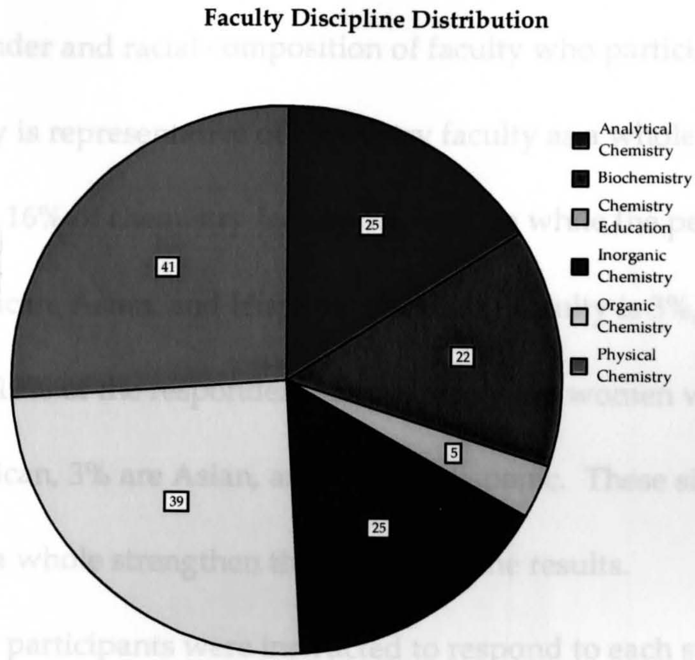


Figure 7. Distribution of faculty by discipline.

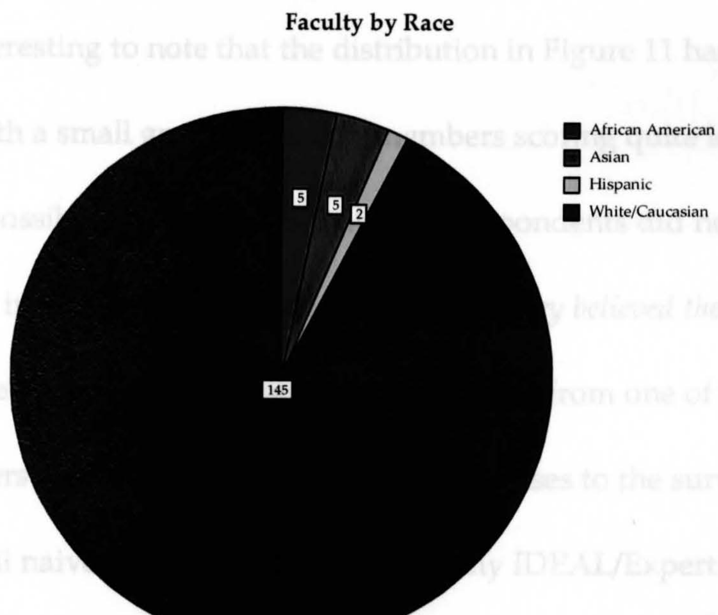


Figure 8. Distribution of faculty by race.

According to statistics gathered by the National Science Foundation in 2004,[36] the gender and racial composition of faculty who participated in this research study is representative of chemistry faculty as a whole. The NSF report indicated that 16% of chemistry faculty are women while the percentage of African American, Asian, and Hispanic chemistry faculty is 3%, 9%, and 3% respectively. 19% of the respondents in this study are women while 3% are African American, 3% are Asian, and 2% are Hispanic. These similarities to the profession as a whole strengthen the validity of the results.

Faculty participants were instructed to respond to each statement in the CHEMX Survey *as they would wish their students to*. The distribution of scores is shown in Figure 11. Possible scores can range from 47 to 235.

It is interesting to note that the distribution in Figure 11 has a bimodal nature to it with a small group of faculty members scoring quite low on the survey. One possible explanation is that these respondents did not follow directions and instead answered the statements as *they believed their students would*. This view is supported by a written comment from one of the low scoring faculty members indicating that his "original responses to the survey represent how my typical naive students respond-- NOT my IDEAL/Expert responses of how they should respond to optimally learn chemistry."

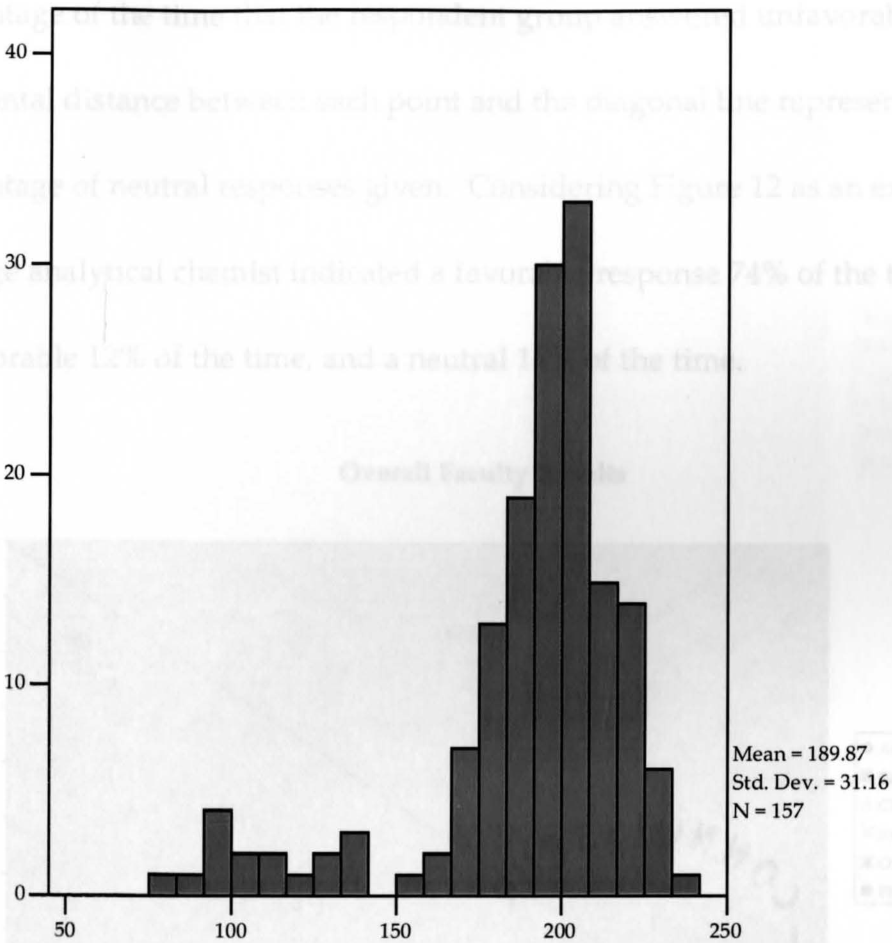


Figure 9. Distribution of CHEMX scores among chemistry faculty members.

Faculty responses were grouped by discipline: analytical chemistry, biochemistry, chemistry education, inorganic chemistry, organic chemistry, or physical chemistry. The agree/disagree plot in Figure 10 shows the overall results for each discipline while those in Figures 11 through 17 show the results for each specific cluster. First introduced by Redish, Saul, and Steinberg in the original MPEX article, these plots concisely display the percentage of the time that the respondent group answered the statements favorably (y-axis) versus the percentage of the time that the respondent group answered unfavorably. The horizontal distance between each point and the diagonal line represents the percentage of neutral responses given. Considering Figure 12 as an example, the average analytical chemist indicated a favorable response 74% of the time, an unfavorable 12% of the time, and a neutral 14% of the time.

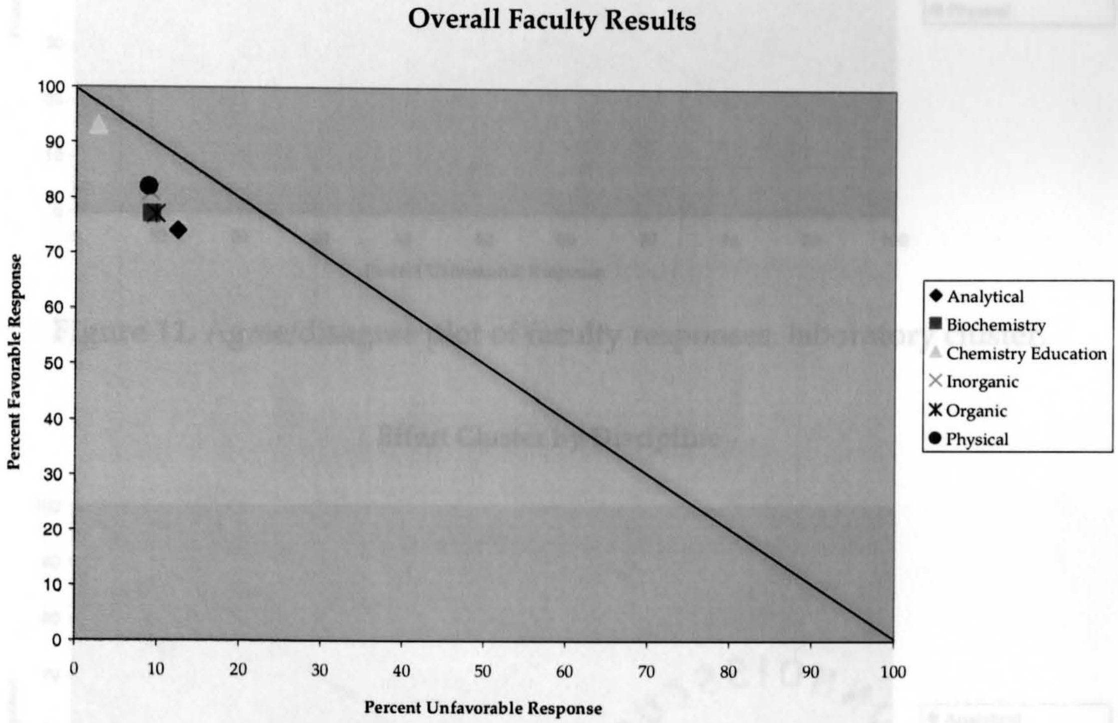


Figure 10. Agree/disagree plot of faculty responses, overall results.

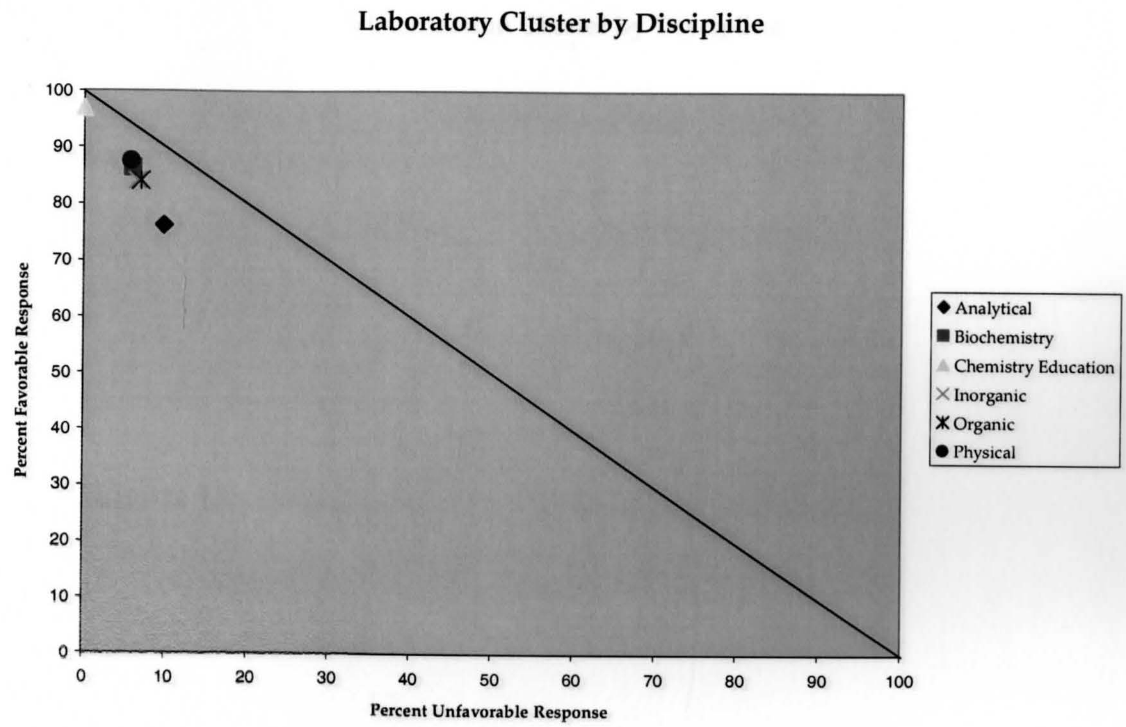


Figure 11. Agree/disagree plot of faculty responses, laboratory cluster.

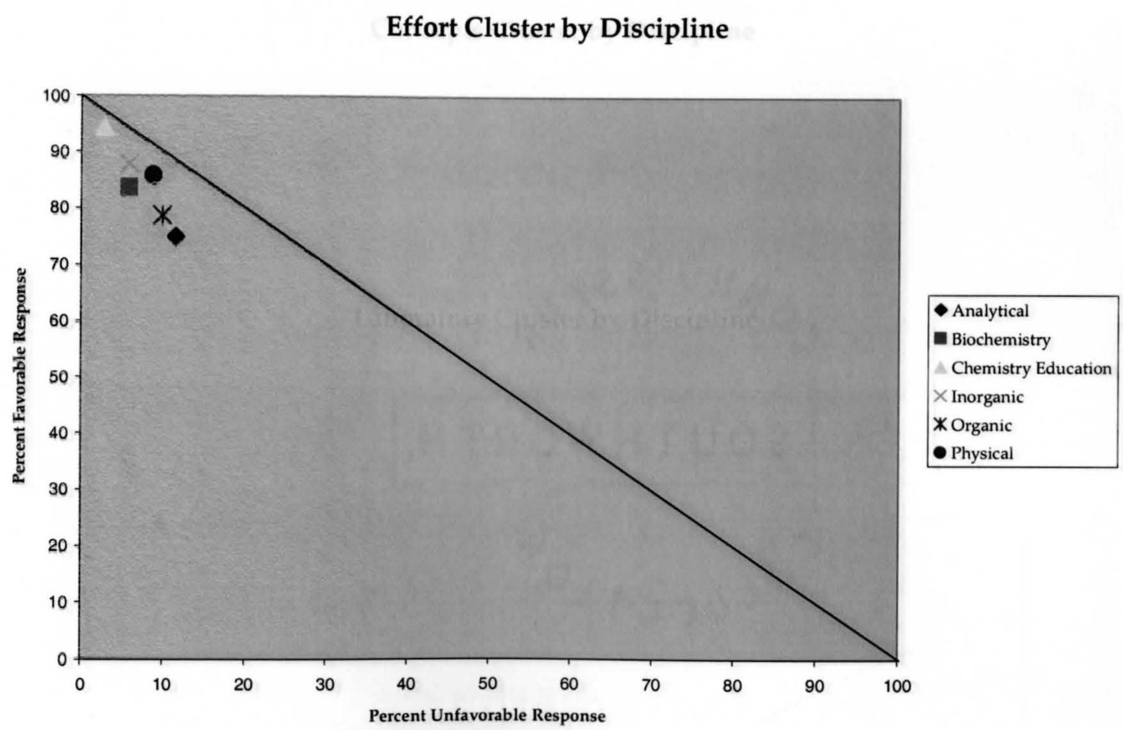


Figure 12. Agree/disagree plot of faculty responses, effort cluster.

Visualization Cluster by Discipline

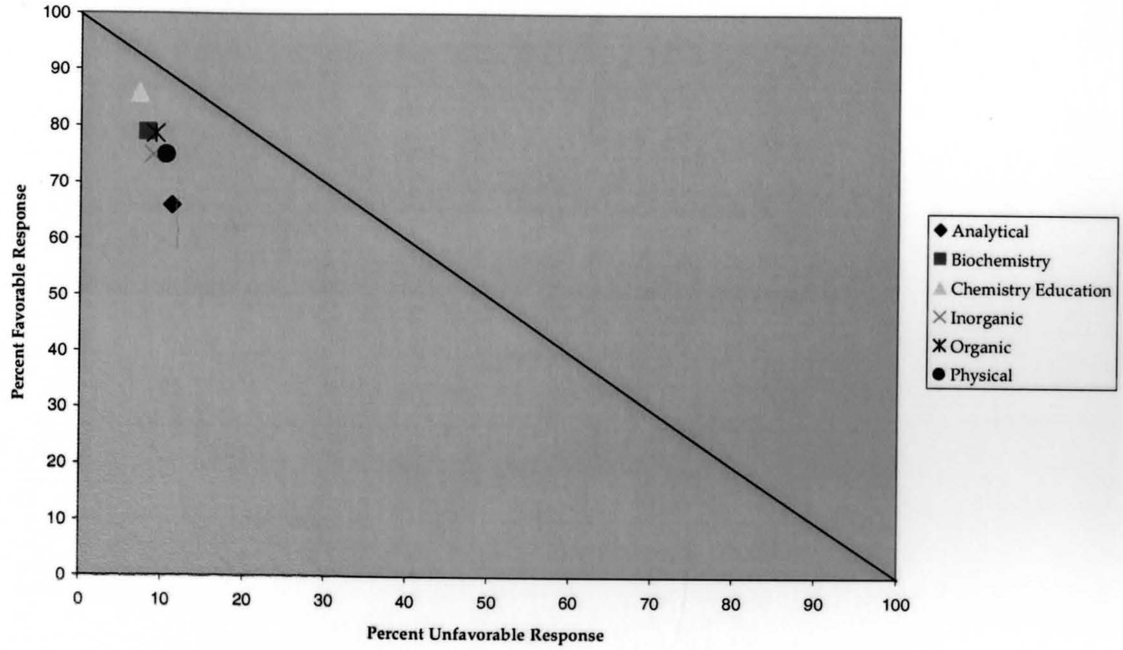


Figure 13. Agree/disagree plot of faculty responses, visualization cluster.

Concepts Cluster by Discipline

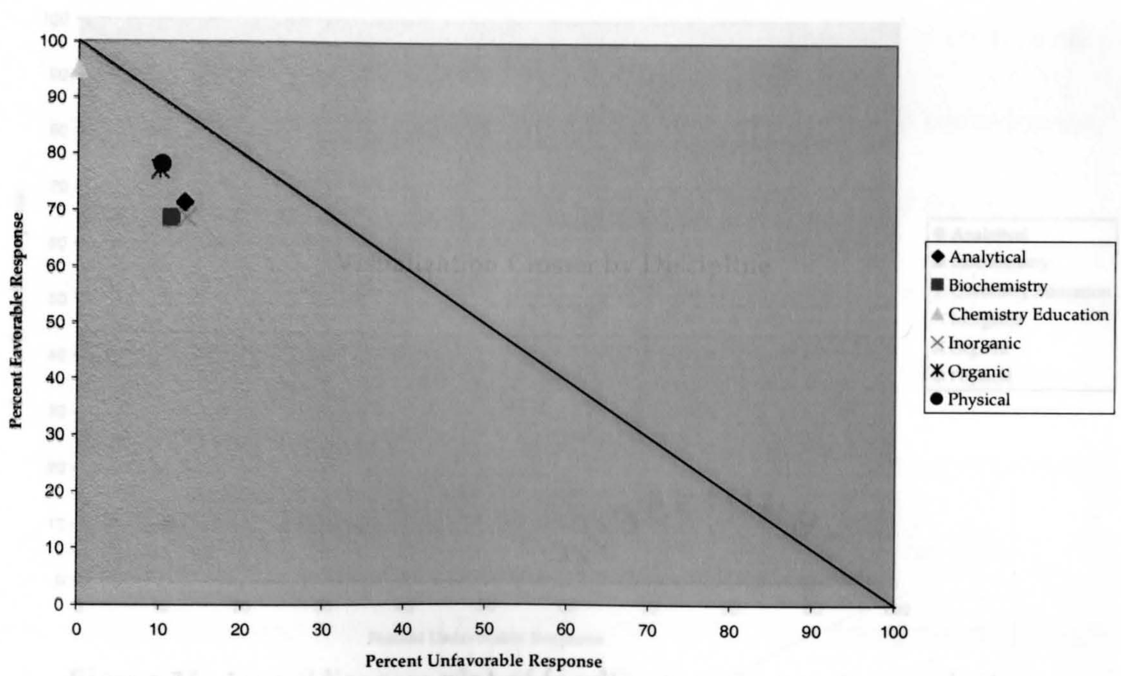


Figure 14. Agree/disagree plot of faculty responses, concepts cluster.

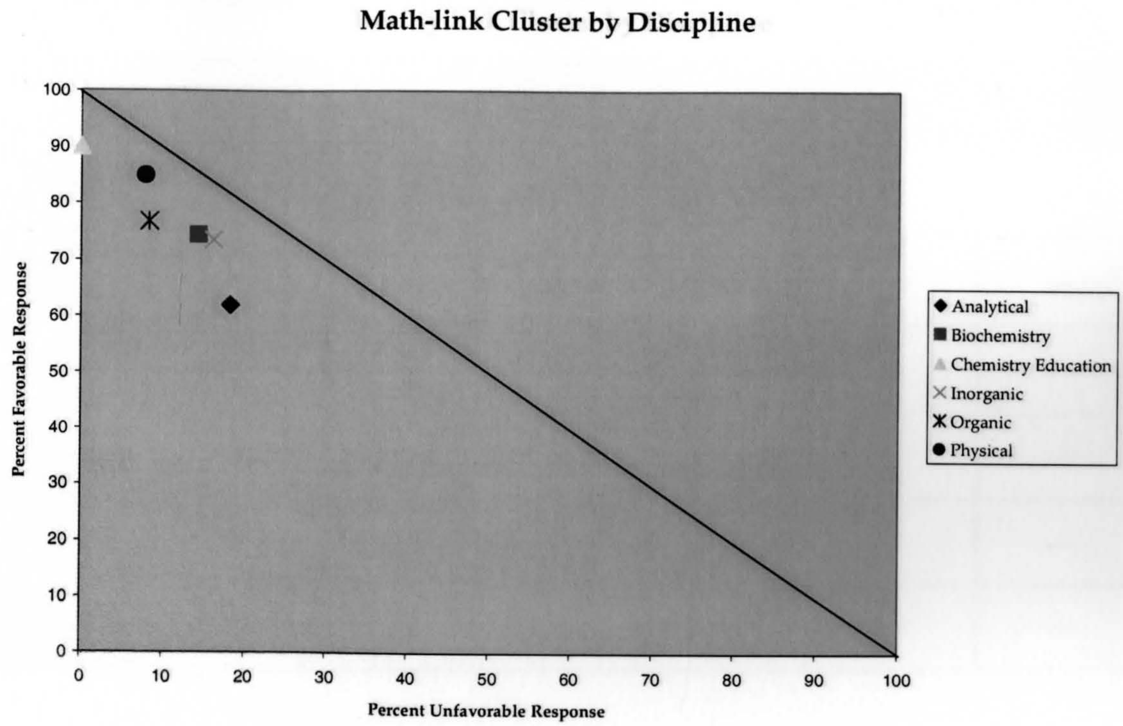


Figure 15. Agree/disagree plot of faculty responses, math-link cluster.

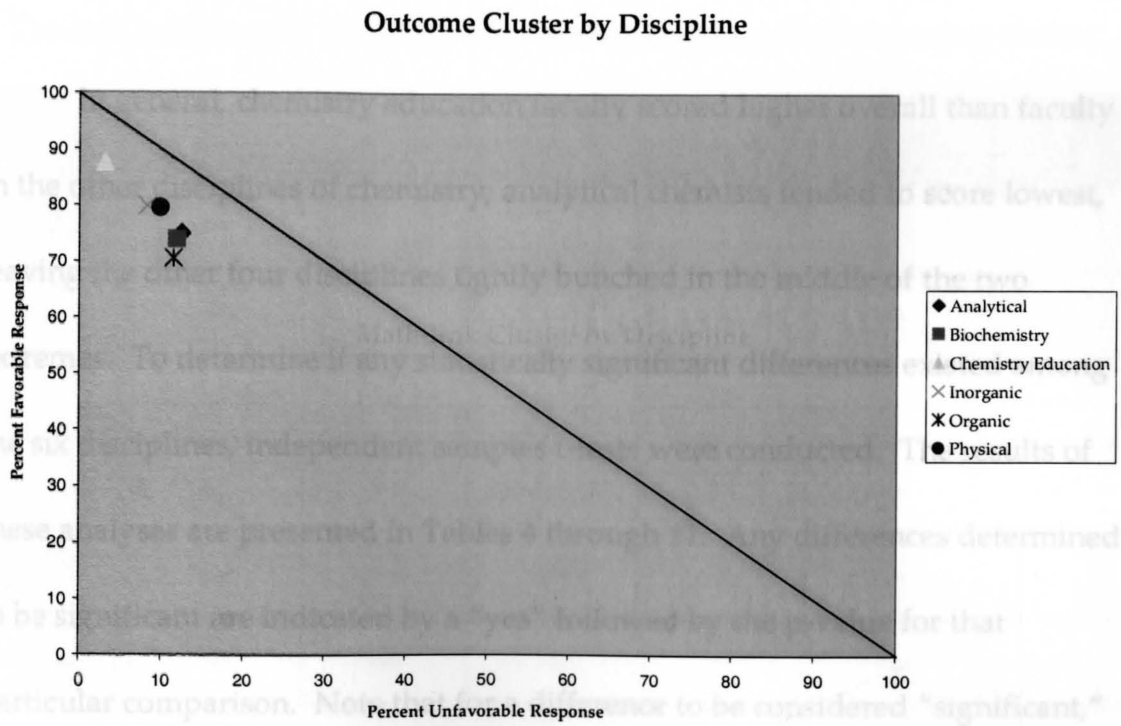


Figure 16. Agree/disagree plot of faculty responses, outcome cluster.

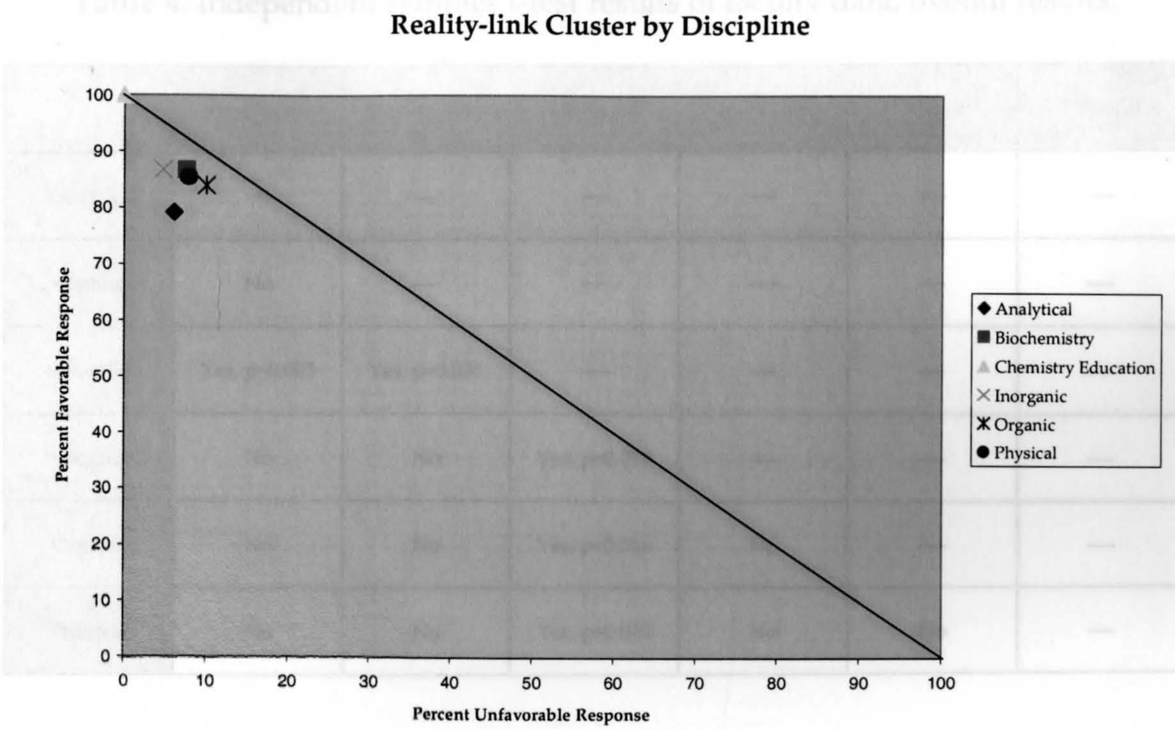


Figure 17. Agree/disagree plot of faculty responses, reality-link cluster.

In general, chemistry education faculty scored higher overall than faculty in the other disciplines of chemistry; analytical chemists tended to score lowest, leaving the other four disciplines tightly bunched in the middle of the two extremes. To determine if any statistically significant differences existed among the six disciplines, independent samples t-tests were conducted. The results of these analyses are presented in Tables 4 through 11. Any differences determined to be significant are indicated by a "yes" followed by the p-value for that particular comparison. Note that for a difference to be considered "significant," the accompanying p-value must be 0.05 or less.

Table 4. Independent samples t-test results of faculty data, overall results.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p=0.005	Yes, p=0.031	----	----	----	----
Inorganic	No	No	Yes, p=0.019	----	----	----
Organic	No	No	Yes, p=0.016	No	----	----
Physical	No	No	Yes, p=0.049	No	No	----

Table 5. Independent samples t-test results of faculty data, laboratory cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p=0.021	No	----	----	----	----
Inorganic	No	No	Yes, p=0.047	----	----	----
Organic	No	No	No	No	----	----
Physical	No	No	No	No	No	----

Table 6. Independent samples t-test results of faculty data, effort cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p=0.001	Yes, p=0.012	----	----	----	----
Inorganic	No	No	Yes, p=0.004	----	----	----
Organic	No	No	Yes, p=0.002	No	----	----
Physical	No	No	Yes, p=0.022	No	No	----

Table 7. Independent samples t-test results of faculty data, concepts cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p=0.007	Yes, p=0.009	----	----	----	----
Inorganic	No	No	Yes, p=0.006	----	----	----
Organic	No	No	Yes, p=0.018	No	----	----
Physical	No	No	Yes, p=0.022	No	No	----

Table 8. Independent samples t-test results of faculty data, math-link cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p=0.002	Yes, p=0.020	----	----	----	----
Inorganic	No	No	Yes, p=0.006	----	----	----
Organic	No	No	Yes, p=0.018	No	----	----
Physical	Yes, p=0.015	No	No	No	No	----

Table 9. Independent samples t-test results of faculty data, outcome cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	No	No	----	----	----	----
Inorganic	No	No	No	----	----	----
Organic	No	No	No	No	----	----
Physical	No	No	No	No	No	----

Table 10. Independent samples t-test results of faculty data, visualization cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	No	No	----	----	----	----
Inorganic	No	No	No	----	----	----
Organic	Yes, p=0.019	No	No	No	----	----
Physical	No	No	No	No	No	----

Table 11. Independent samples t-test results of faculty data, reality-link cluster.

	Analytical	Biochemistry	Chem Ed	Inorganic	Organic	Physical
Analytical	----	----	----	----	----	----
Biochemistry	No	----	----	----	----	----
Chem Ed	Yes, p<0.001	Yes, p=0.004	----	----	----	----
Inorganic	No	No	Yes, p<0.001	----	----	----
Organic	No	No	Yes, p<0.001	No	----	----
Physical	No	No	Yes, p<0.001	No	No	----

Student Results – Small, Selective Public University (n=342)

Students enrolled in General Chemistry I (n=337), Inorganic Chemistry (n=5), and Instrumental Analysis (n=5) - the latter two both being junior-level courses at SSPU - participated in surveying. Agree/disagree plots for the overall results and for each cluster are included in Figures 18-25. To determine whether any significant changes occurred across the three time periods, a One-way Analysis of Variance (ANOVA) was conducted. The results of this analysis are included in Table 12.

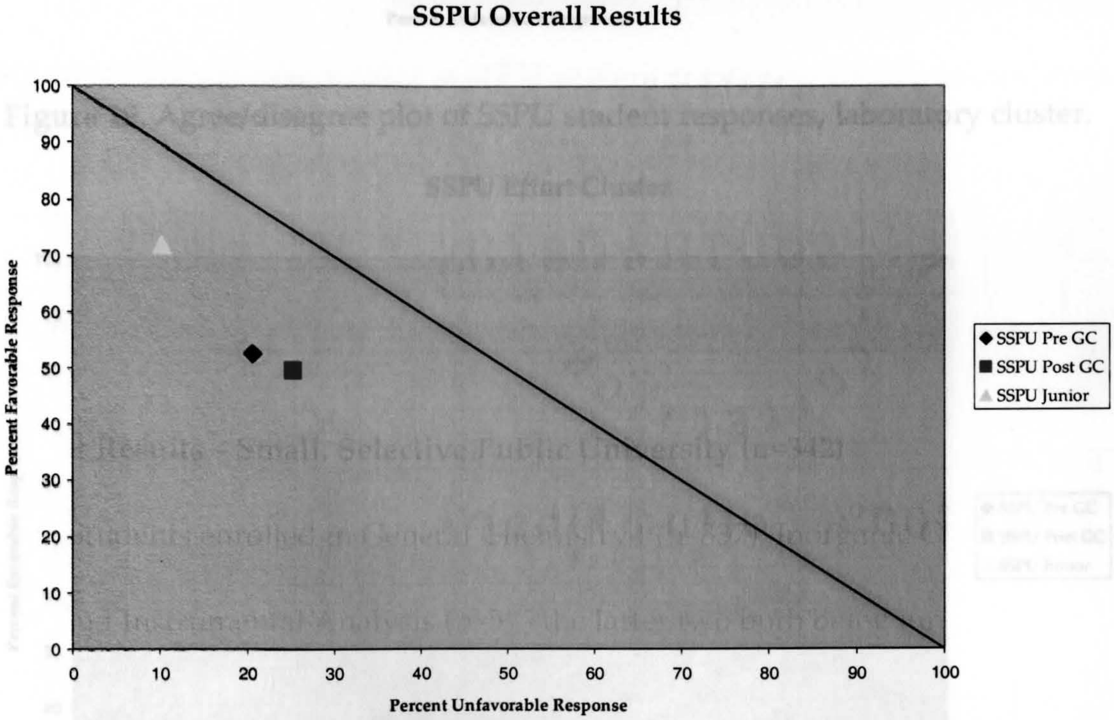


Figure 18. Agree/disagree plot of SSPU student responses, overall results.

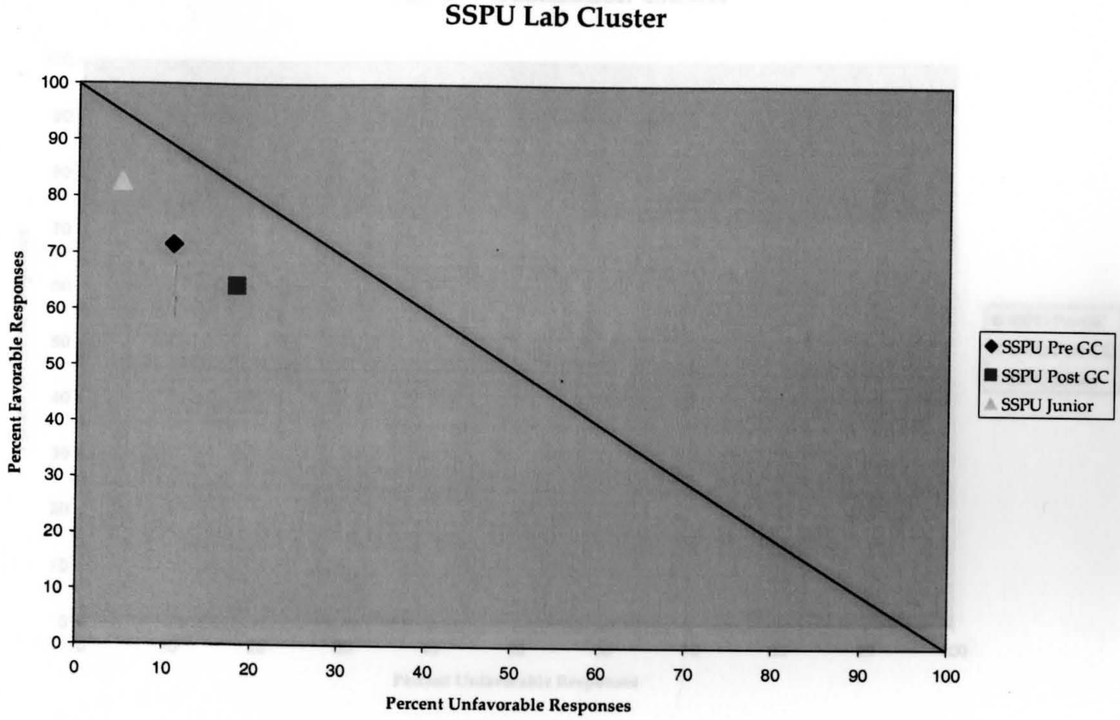


Figure 19. Agree/disagree plot of SSPU student responses, laboratory cluster.

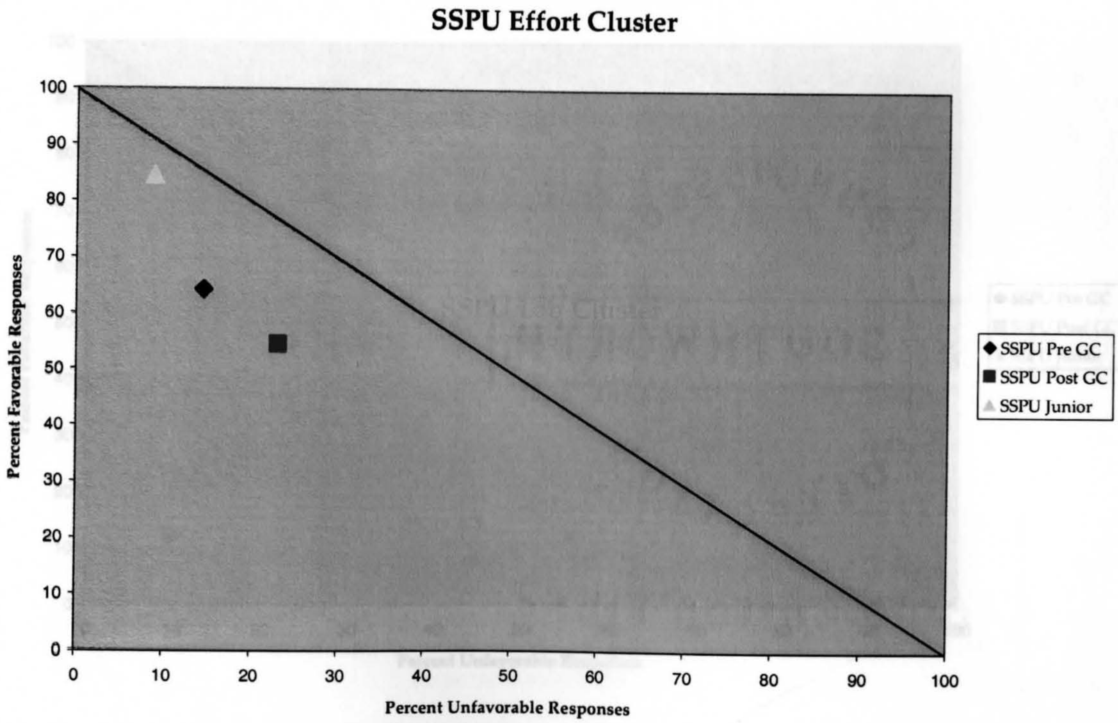


Figure 20. Agree/disagree plot of SSPU student responses, effort cluster.

SSPU Visualization Cluster

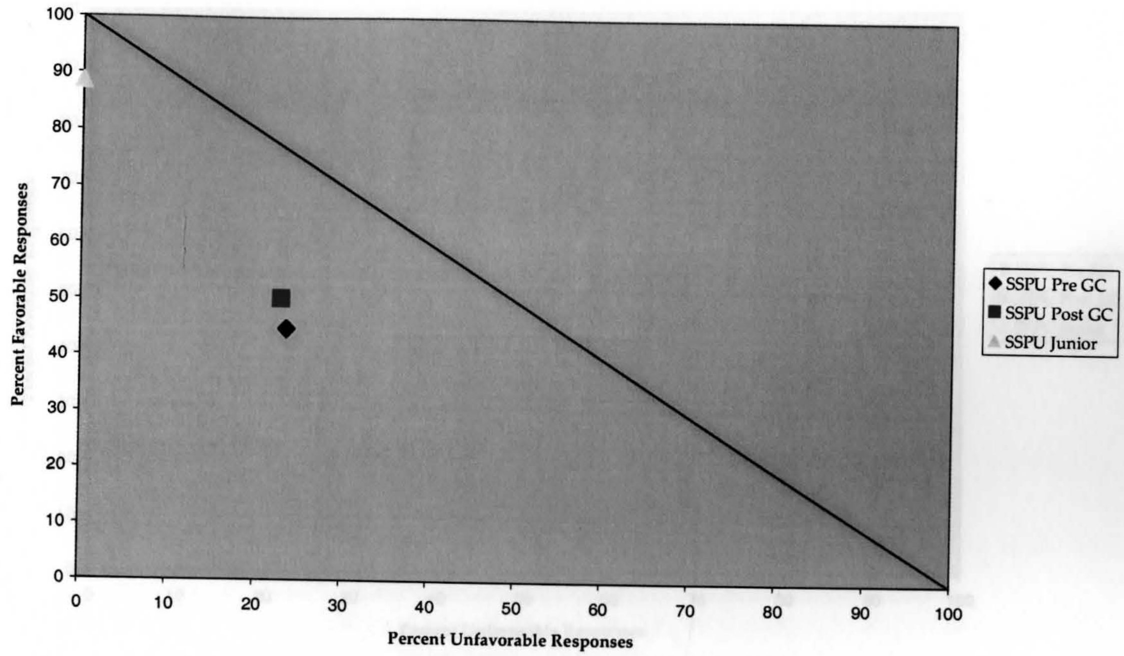


Figure 21. Agree/disagree plot of SSPU student responses, visualization cluster.

SSPU Concept Cluster

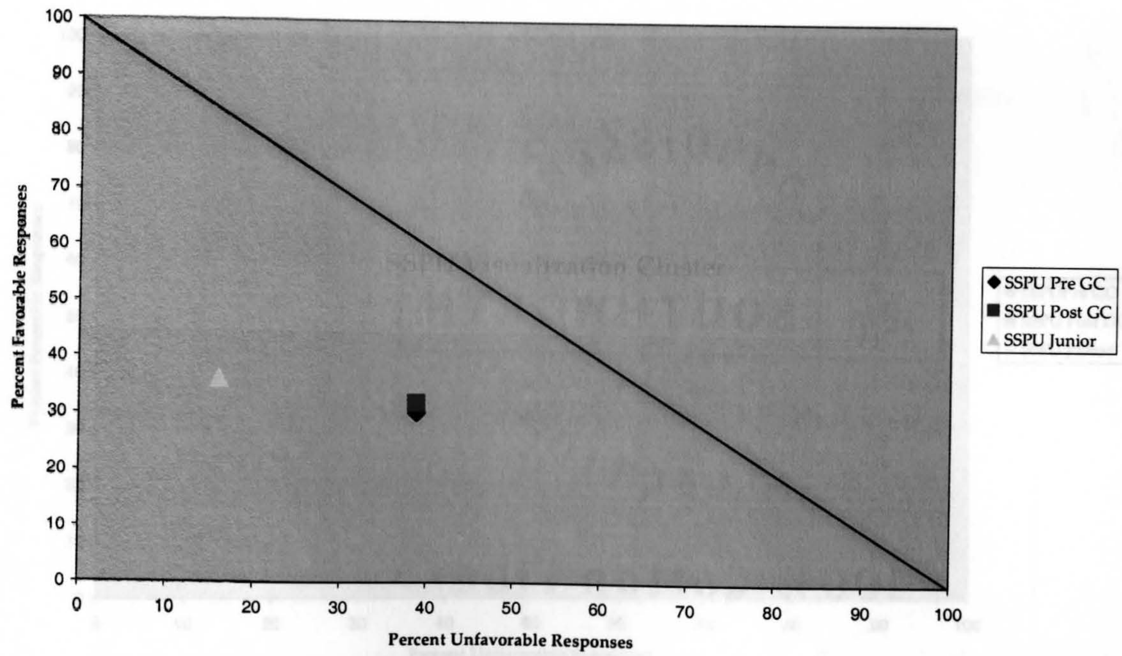


Figure 22. Agree/disagree plot of SSPU student responses, concepts cluster

SSPU Math-Link Cluster

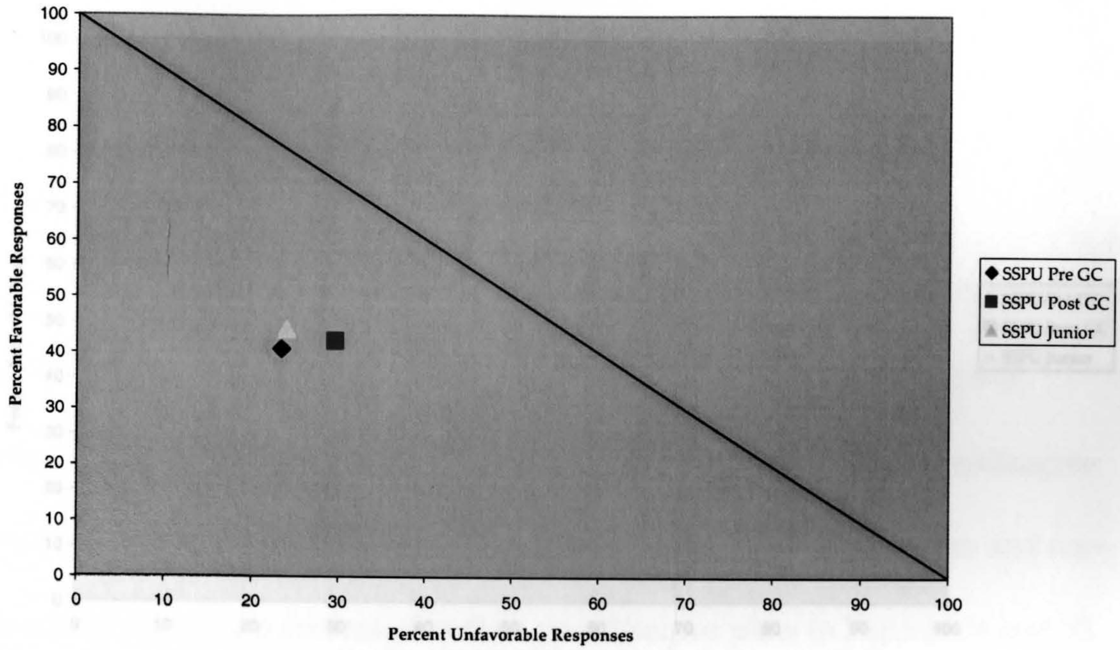


Figure 23. Agree/disagree plot of SSPU student responses, math-link cluster

SSPU Outcome Cluster

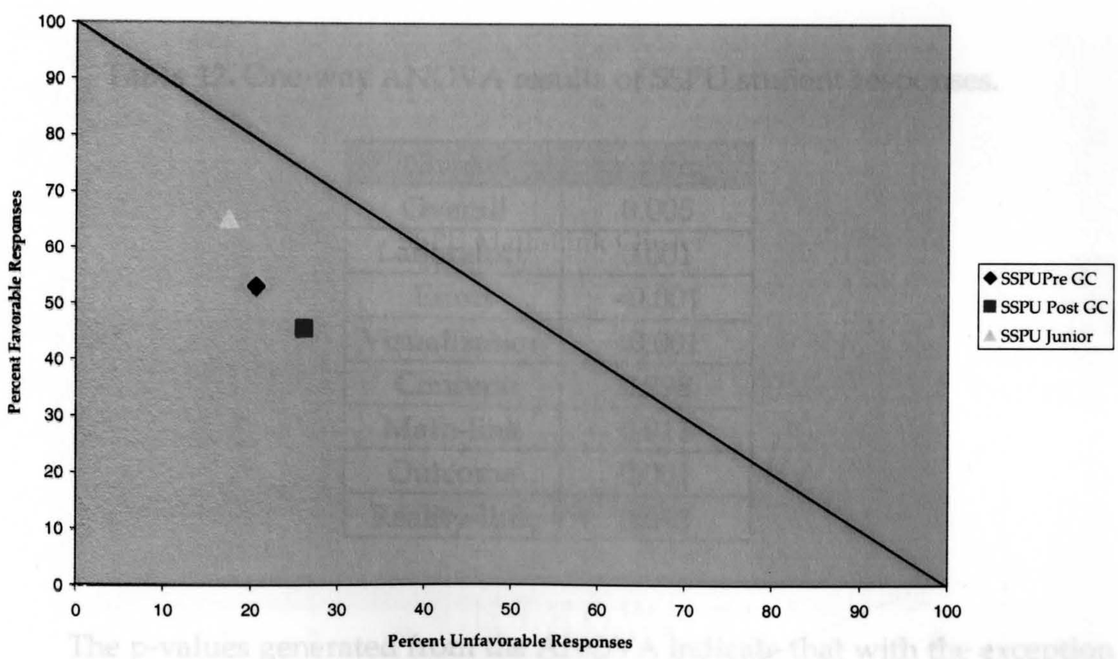


Figure 24. Agree/disagree plot of SSPU student responses, outcome cluster.

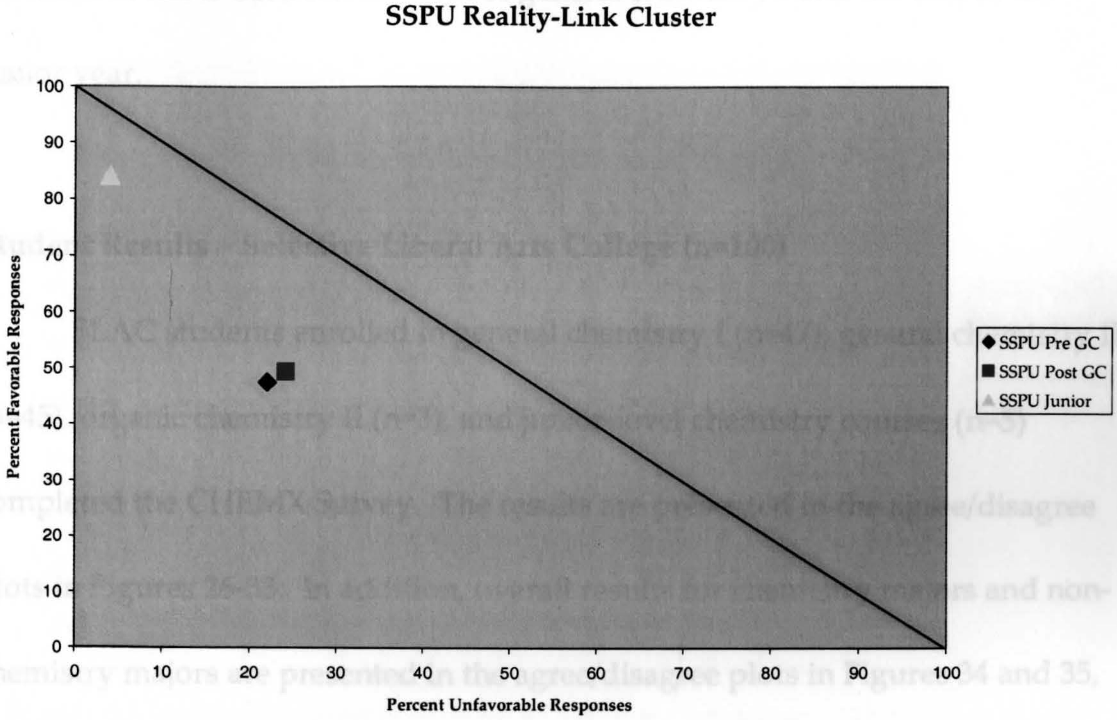


Figure 25. Agree/disagree plot of SSPU student responses, reality-link cluster.

Table 12. One-way ANOVA results of SSPU student responses.

Cluster	p-value
Overall	0.005
Laboratory	0.001
Effort	<0.001
Visualization	<0.001
Concept	0.298
Math-link	0.911
Outcome	0.001
Reality-link	0.043

The p-values generated from the ANOVA indicate that with the exception of the Math-link cluster, a statistically significant improvement in CHEMX scores occurred at SSPU between the start of general chemistry I and the end of the Junior year.

Student Results – Selective Liberal Arts College (n=100)

SLAC students enrolled in general chemistry I (n=47), general chemistry II (n=45), organic chemistry II (n=3), and junior-level chemistry courses (n=5) completed the CHEMX Survey. The results are presented in the agree/disagree plots in Figures 26-33. In addition, overall results for chemistry majors and non-chemistry majors are presented in the agree/disagree plots in Figures 34 and 35, respectively.

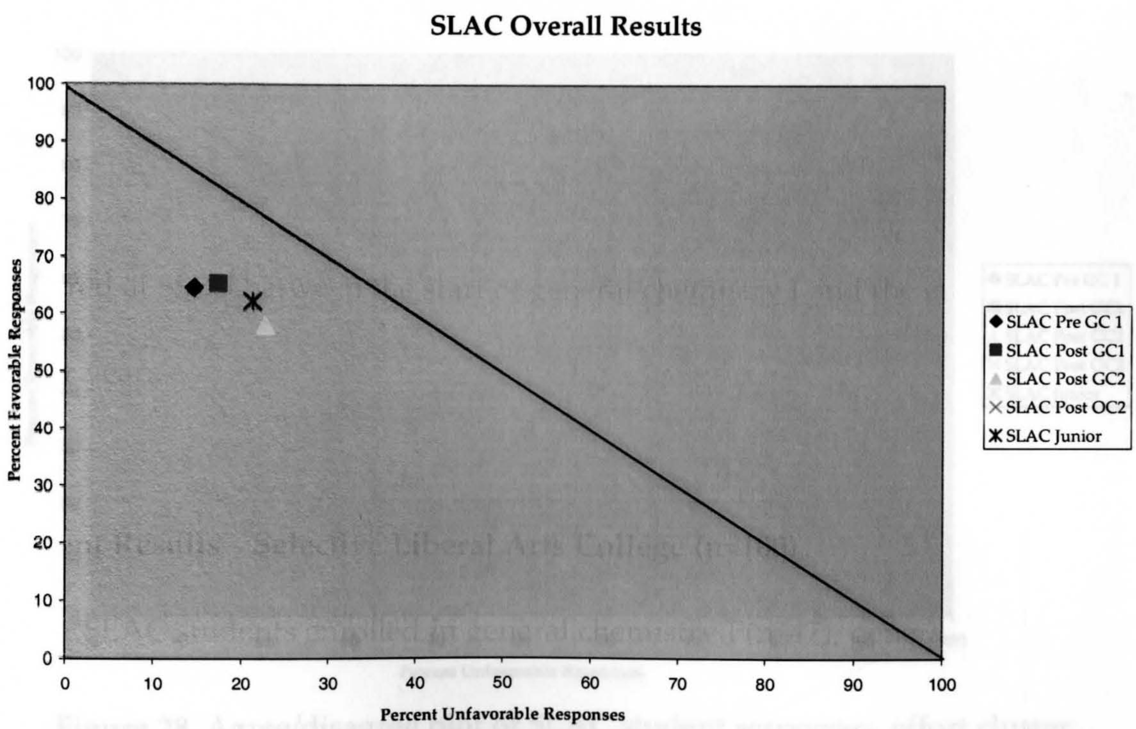


Figure 26. Agree/disagree plots of SLAC student responses, overall results.

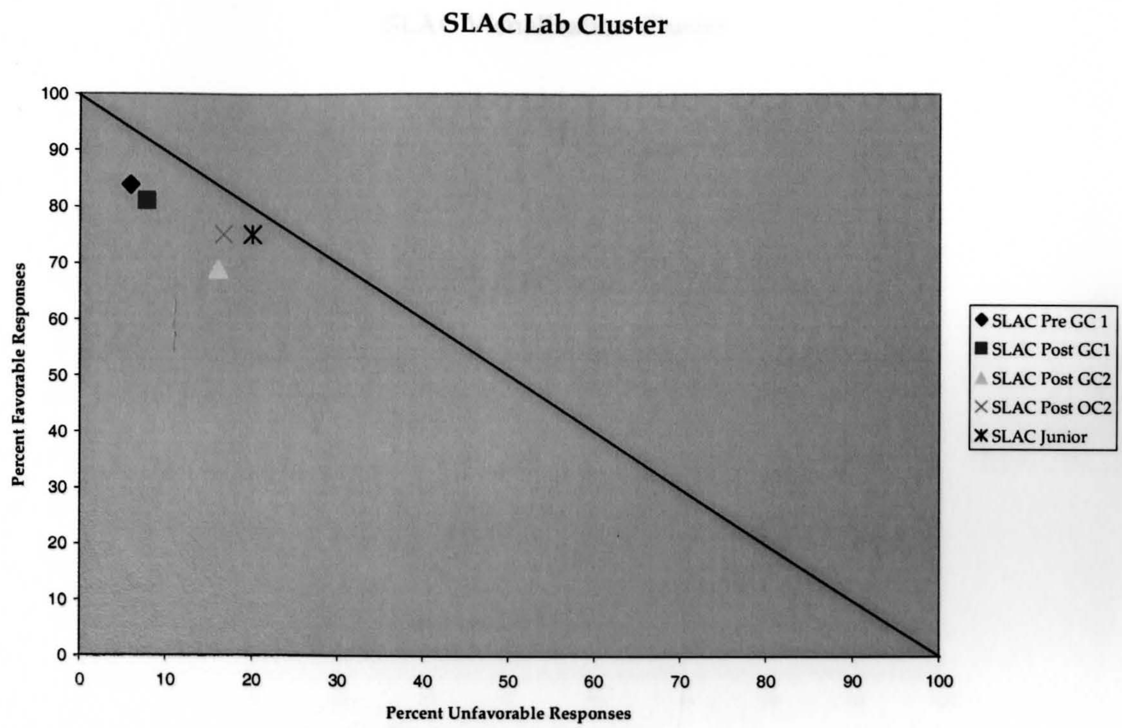


Figure 27. Agree/disagree plot of SLAC student responses, laboratory cluster.

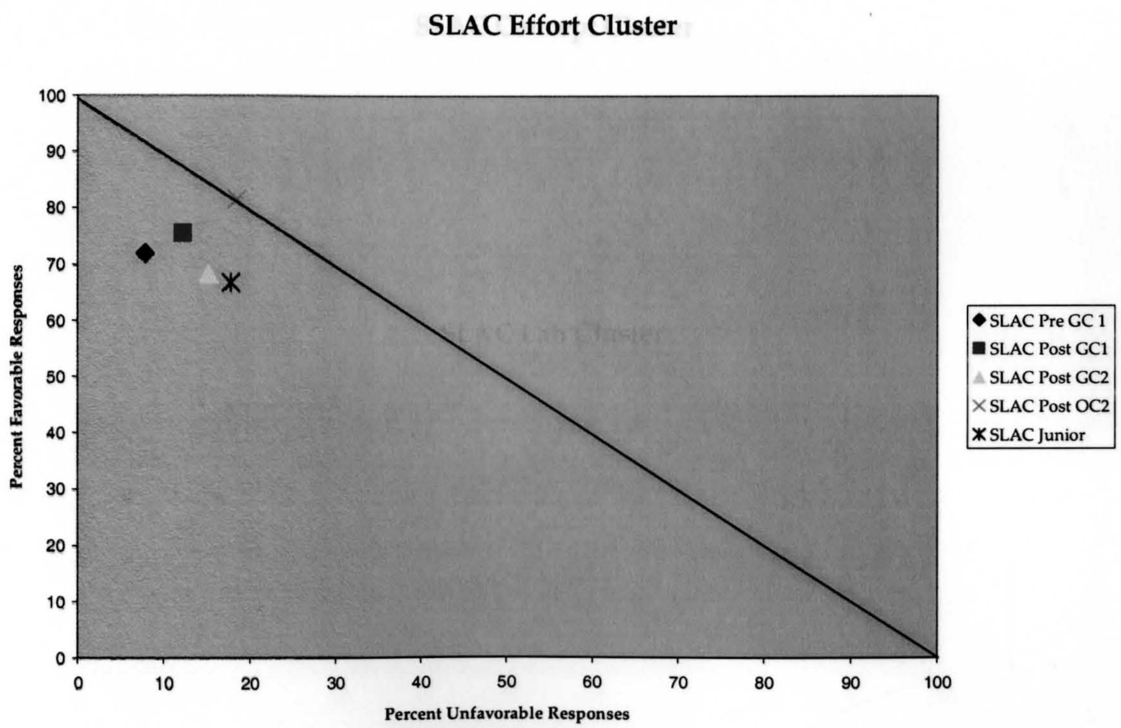


Figure 28. Agree/disagree plot of SLAC student responses, effort cluster.

SLAC Visualization Cluster

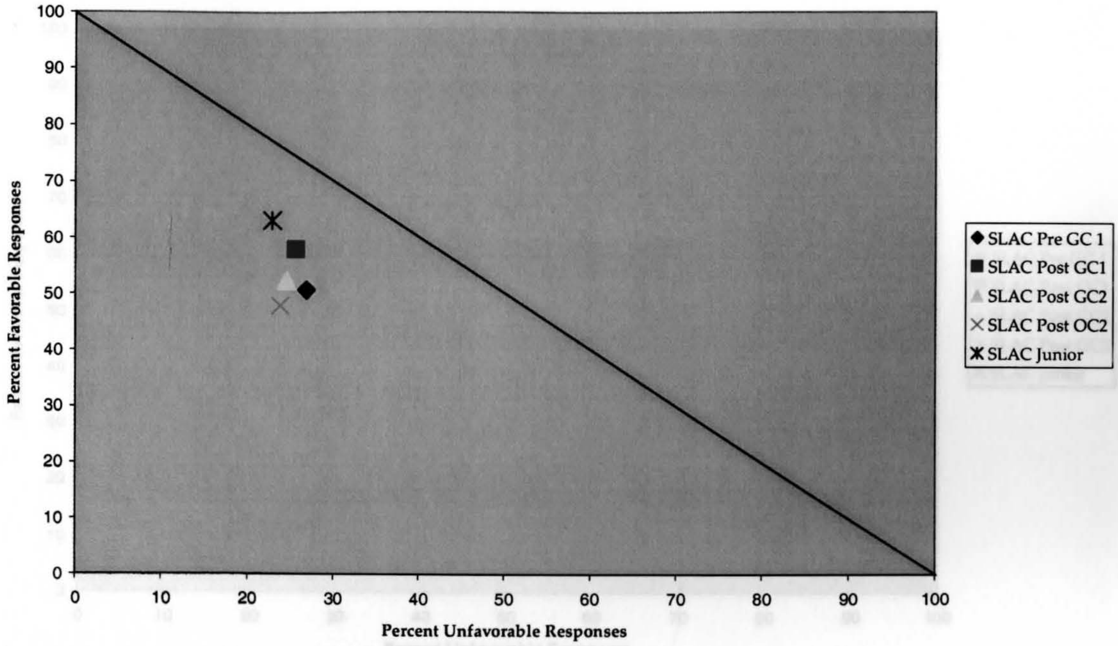


Figure 29. Agree/disagree plot of SLAC student responses, visualization cluster.

SLAC Concept Cluster

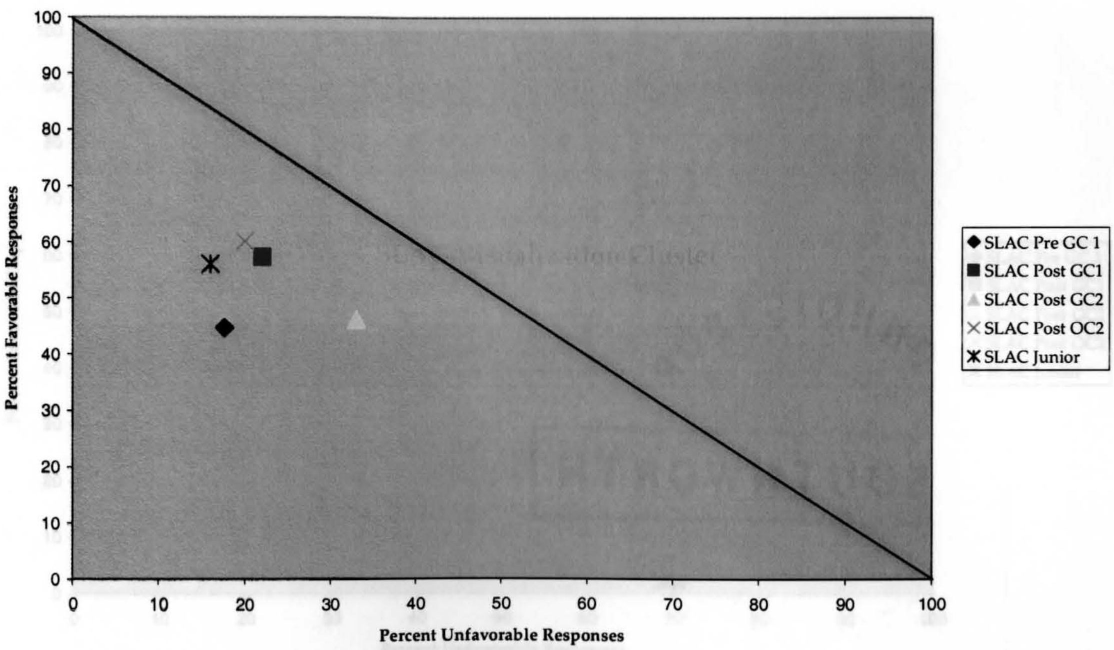


Figure 30. Agree/disagree plot of SLAC student responses, concept cluster.

SLAC Math-Link Cluster

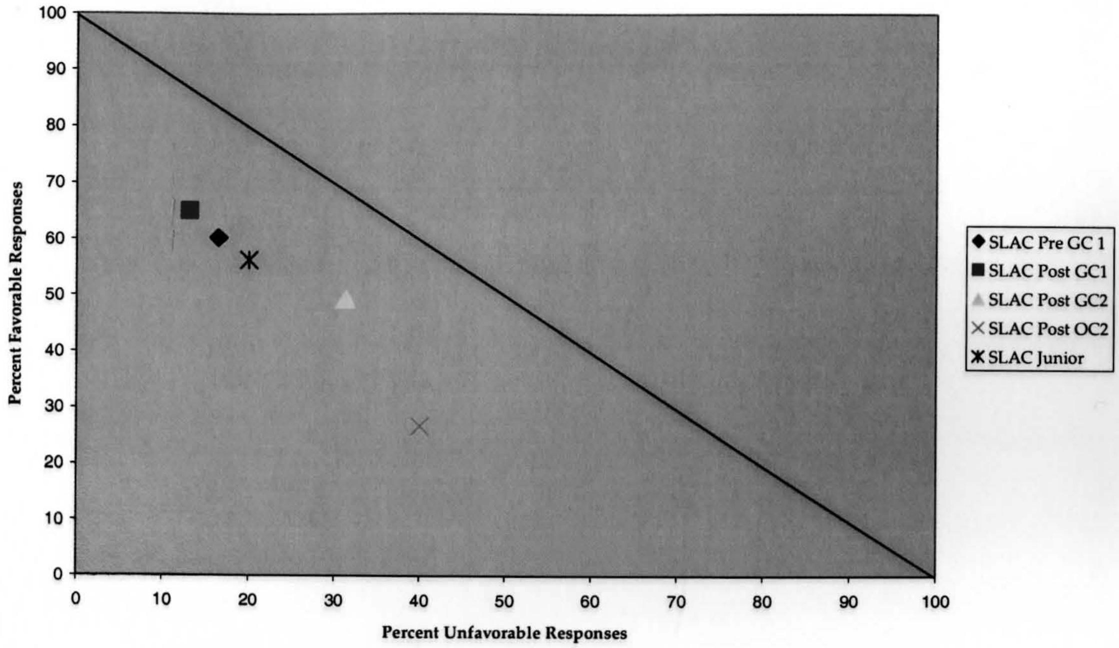


Figure 31. Agree/disagree plot of SLAC student responses, math-link cluster.

SLAC Outcome Cluster

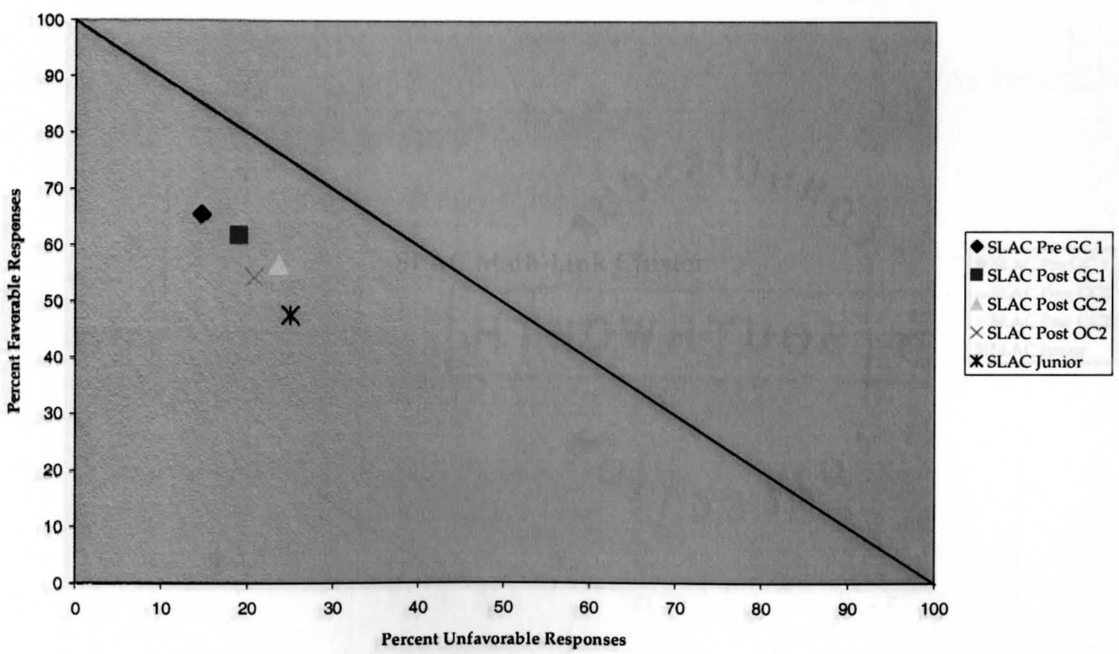


Figure 32. Agree/disagree plot of SLAC student responses, outcome cluster.

SLAC Reality-Link Cluster

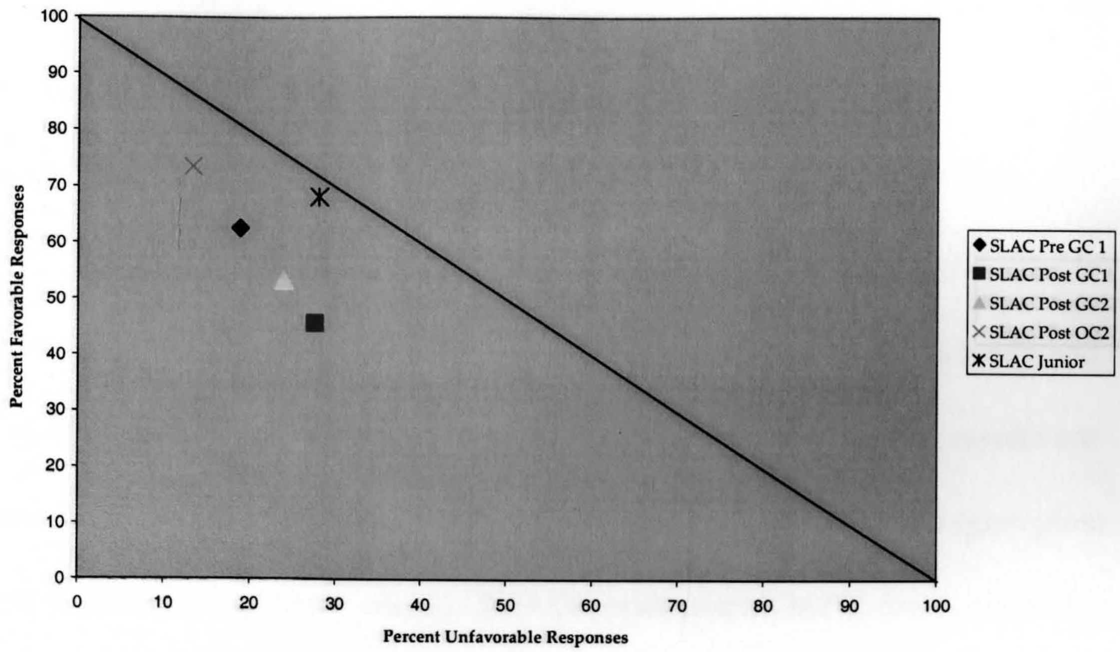


Figure 33. Agree/disagree plot of SLAC student responses, reality-link cluster.

SLAC Majors Overall Results

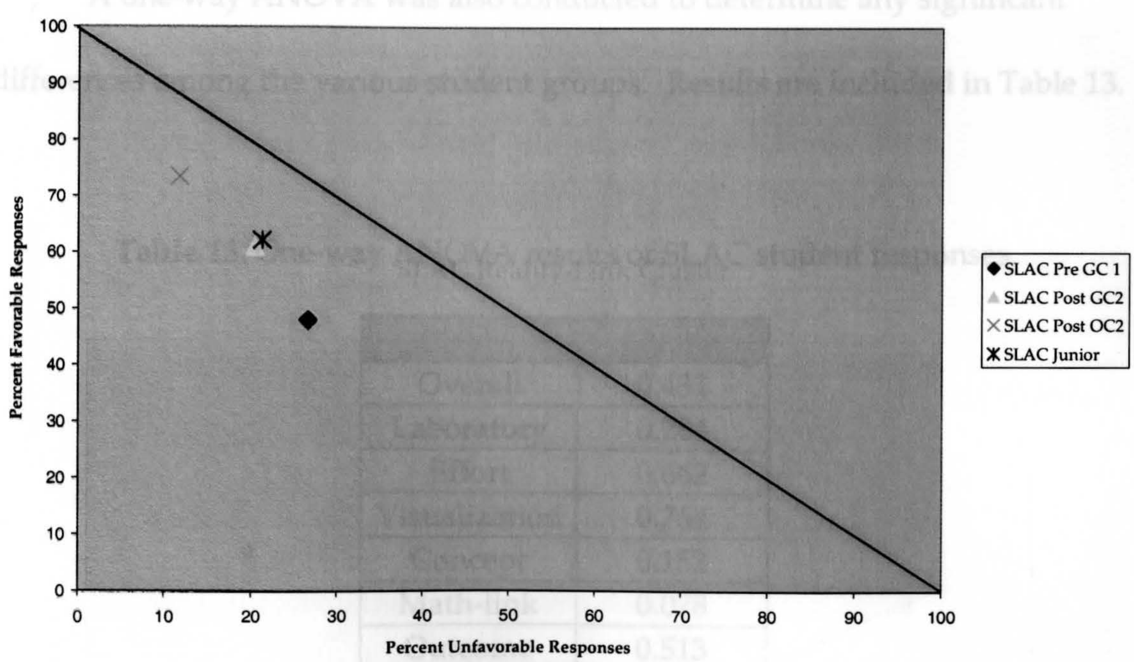


Figure 34. Agree/disagree plot of SLAC chemistry majors, overall results.

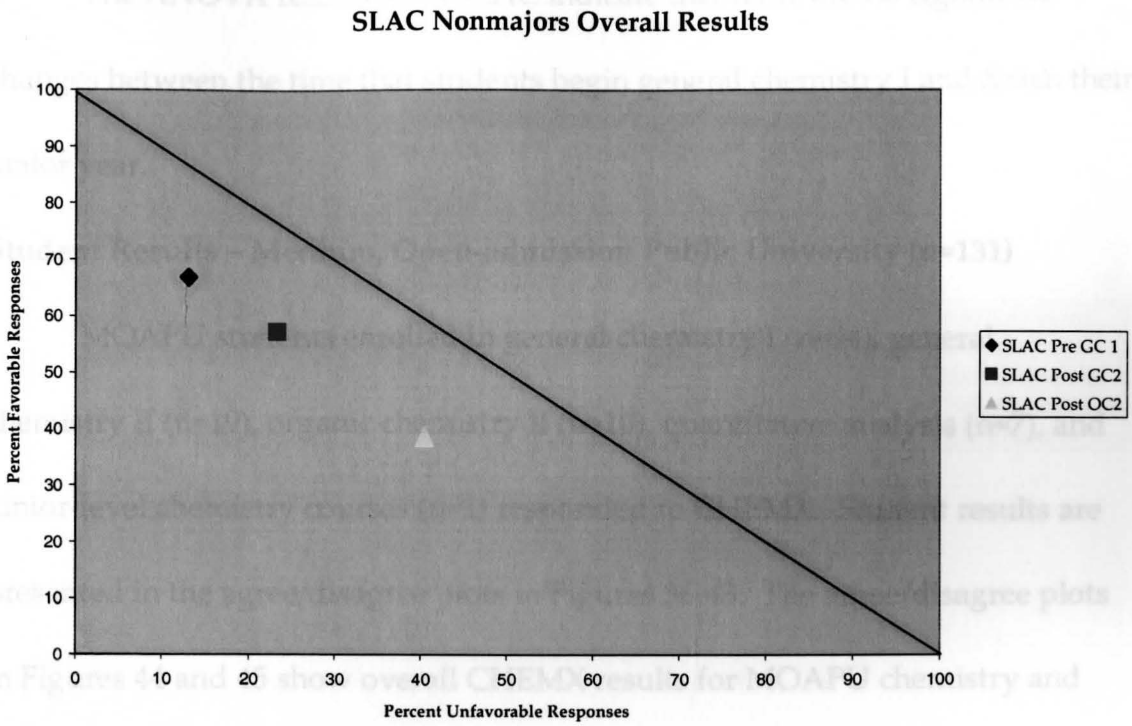


Figure 35. Agree/disagree plot of SLAC non-chemistry majors, overall results.

A one-way ANOVA was also conducted to determine any significant differences among the various student groups. Results are included in Table 13.

Table 13. One-way ANOVA results of SLAC student responses.

Cluster	p-value
Overall	0.431
Laboratory	0.284
Effort	0.662
Visualization	0.764
Concept	0.152
Math-link	0.078
Outcome	0.513
Reality-link	0.398

The ANOVA results from SLAC indicate that there are no significant changes between the time that students begin general chemistry I and finish their junior year.

Student Results – Medium, Open-admission Public University (n=131)

MOAPU students enrolled in general chemistry I (n=94), general chemistry II (n=19), organic chemistry II (n=10), quantitative analysis (n=7), and junior-level chemistry courses (n=1) responded to CHEMX. Student results are presented in the agree/disagree plots in Figures 36-43. The agree/disagree plots in Figures 44 and 45 show overall CHEMX results for MOAPU chemistry and biochemistry majors and MOAPU non-chemistry majors.

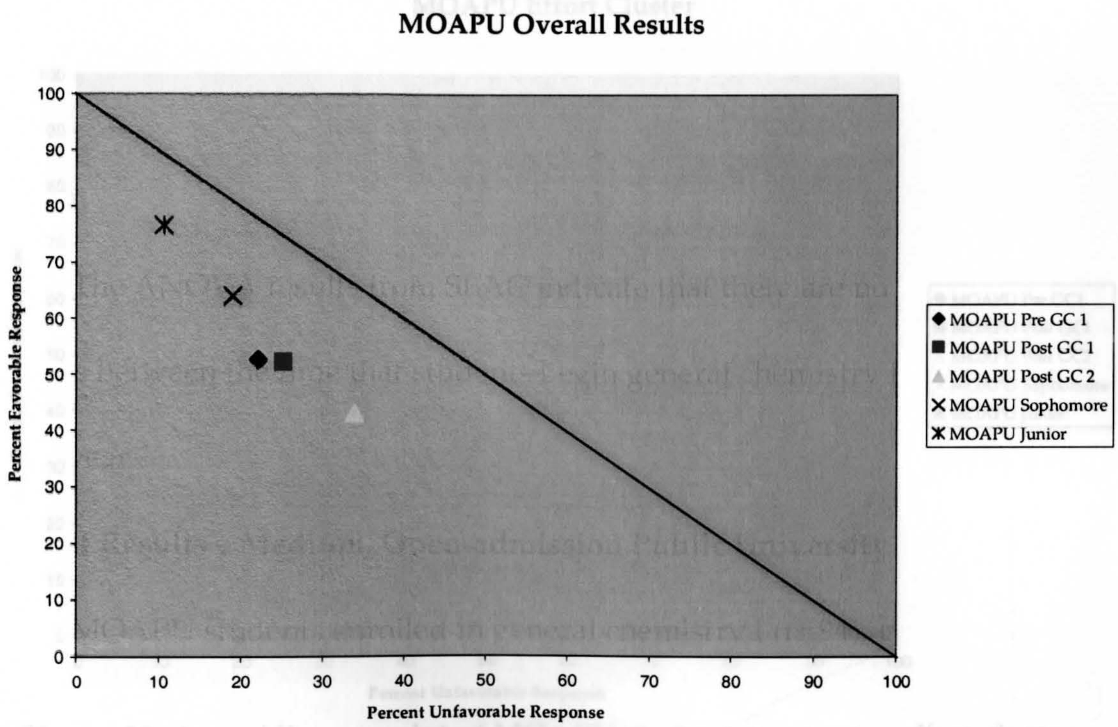


Figure 36. Agree/disagree plot of MOAPU student responses, overall results.

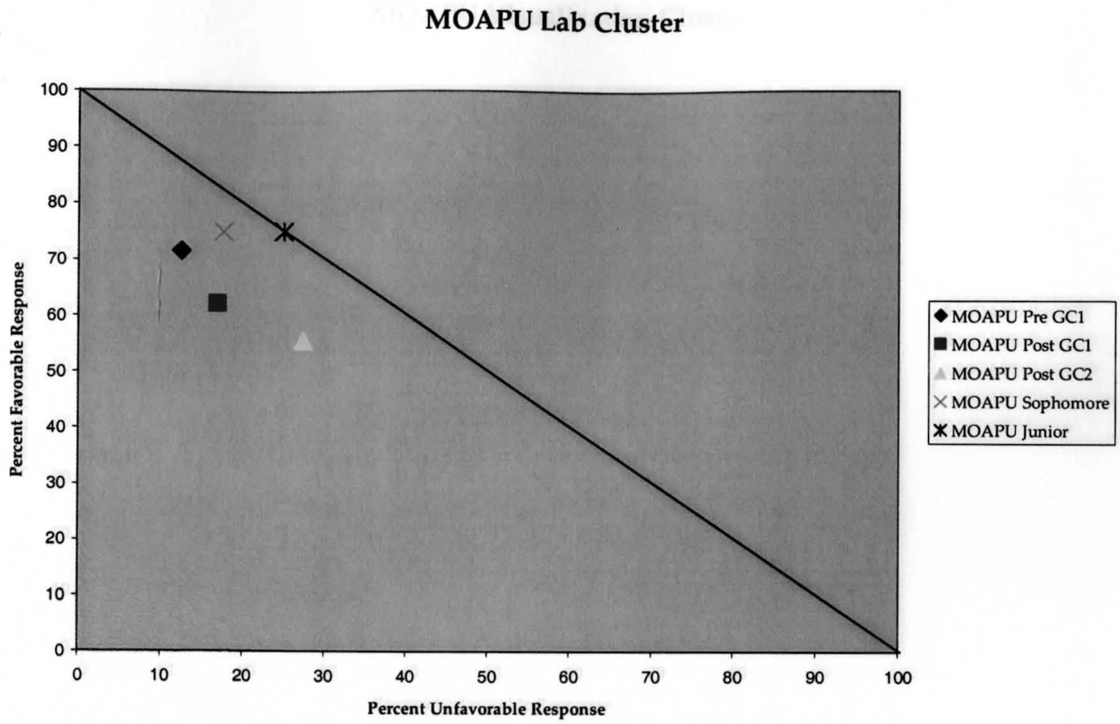


Figure 37. Agree/disagree plot of MOAPU student responses, laboratory cluster.

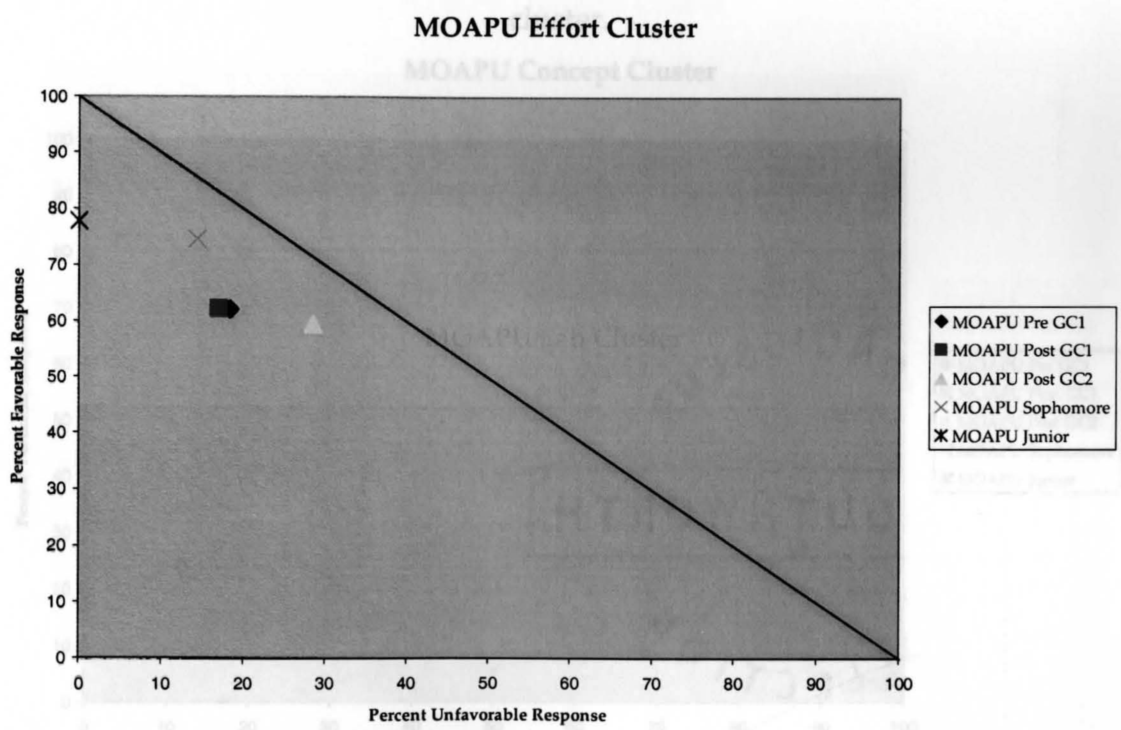


Figure 38. Agree/disagree plot of MOAPU student responses, effort cluster.

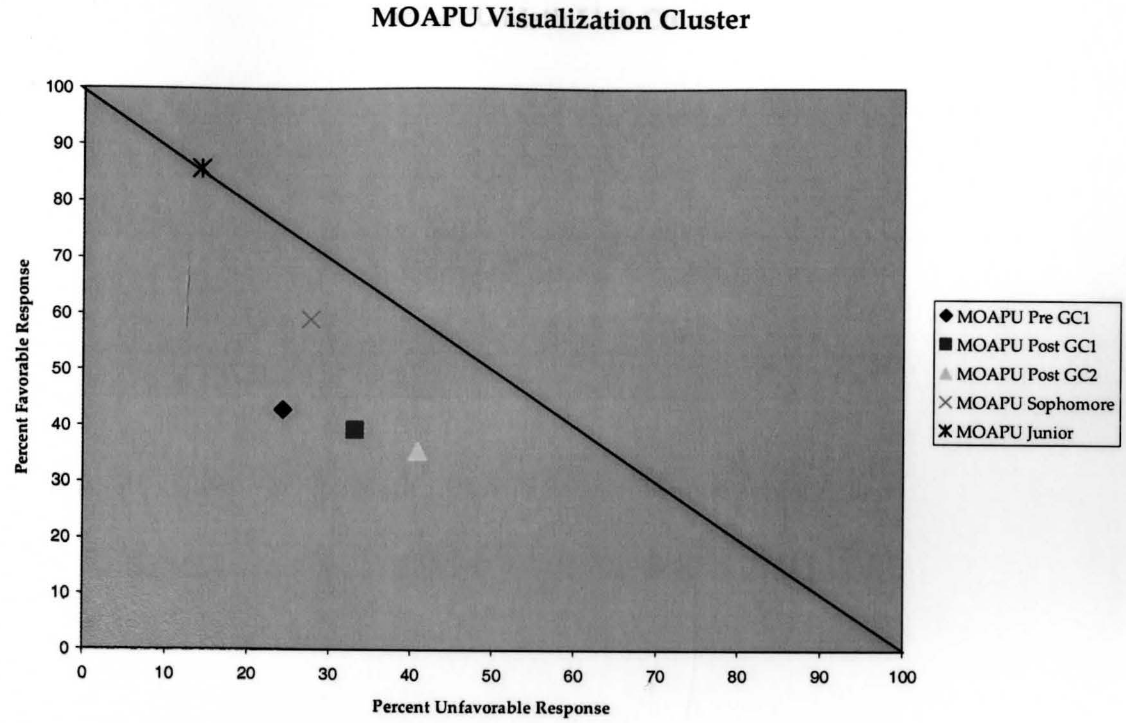


Figure 39. Agree/disagree plot of MOAPU student responses, visualization cluster.

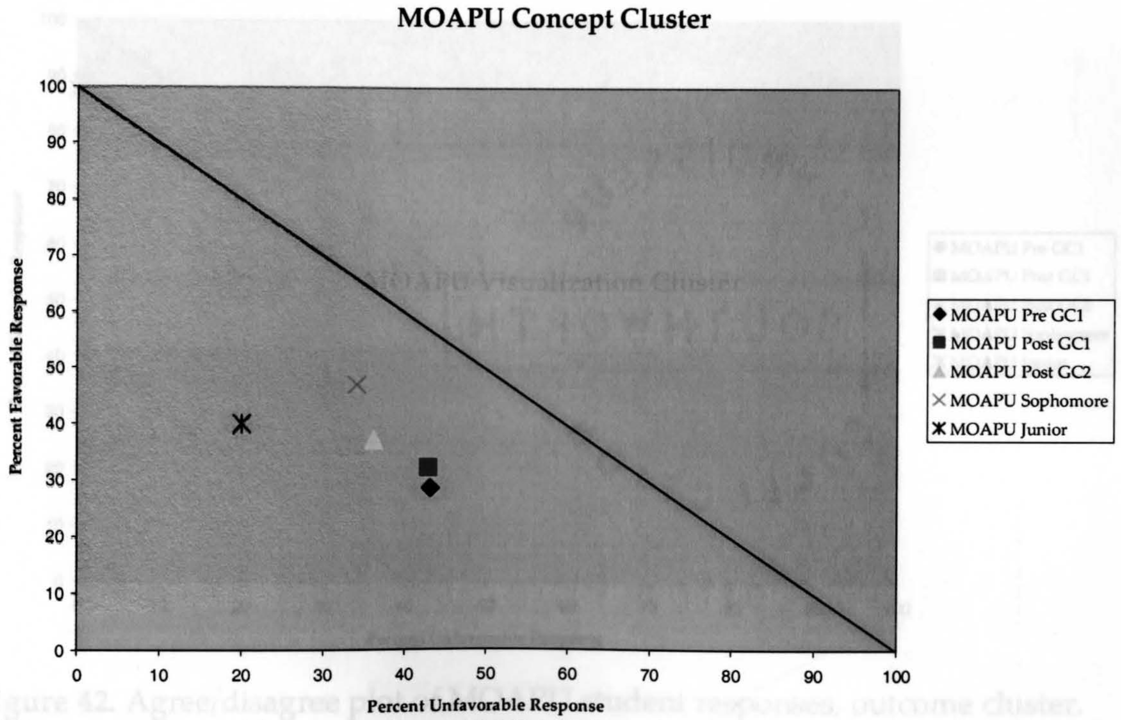


Figure 40. Agree/disagree plot of MOAPU student responses, concept cluster.

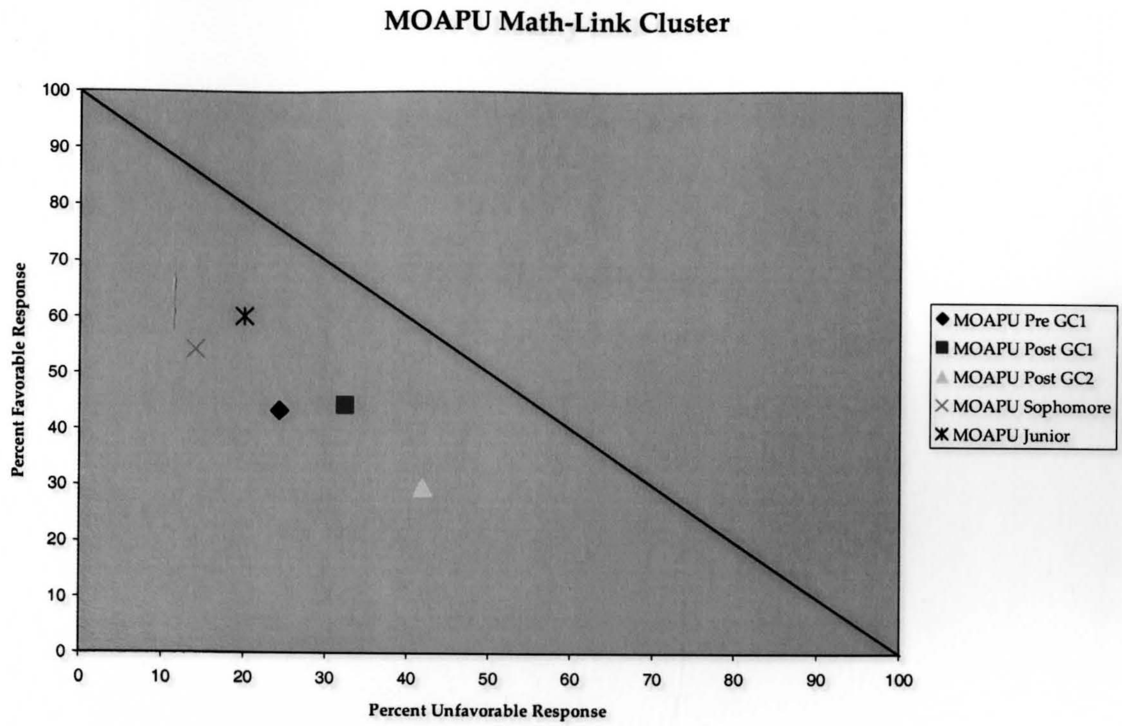


Figure 41. Agree/disagree plot of MOAPU student responses, math-link cluster.

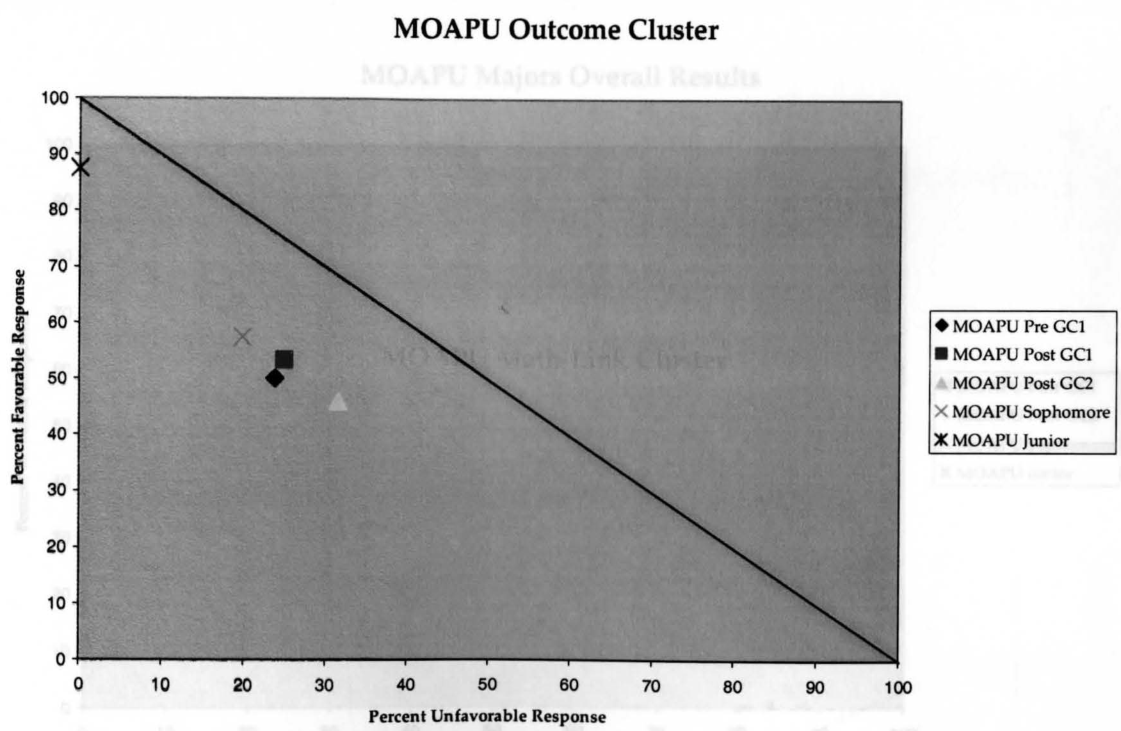


Figure 42. Agree/disagree plot of MOAPU student responses, outcome cluster.

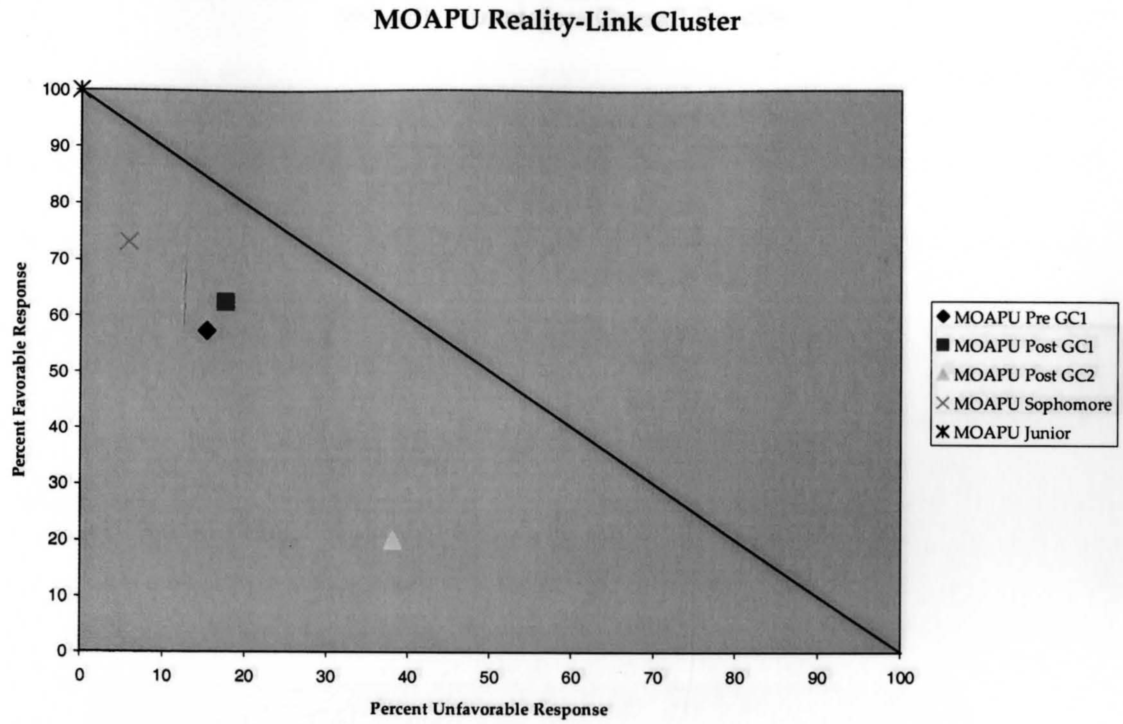


Figure 43. Agree/disagree plot of MOAPU student responses, reality-link cluster.

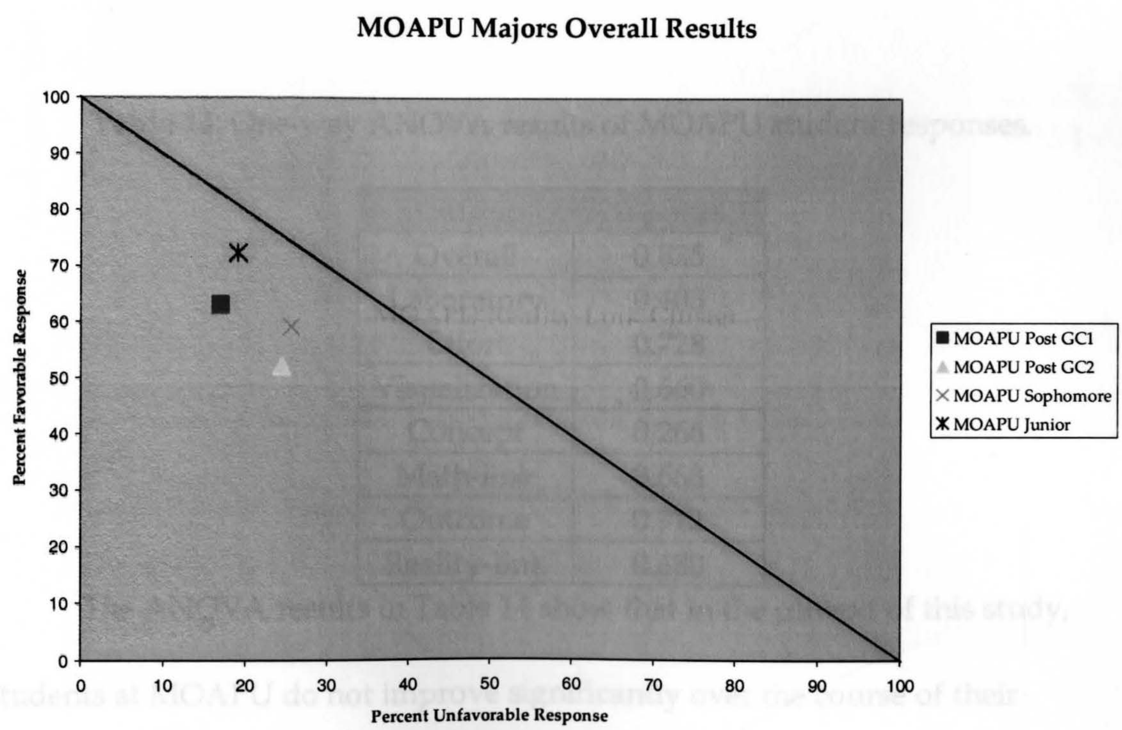


Figure 44. Agree/disagree plot of MOAPU chemistry majors, overall results.

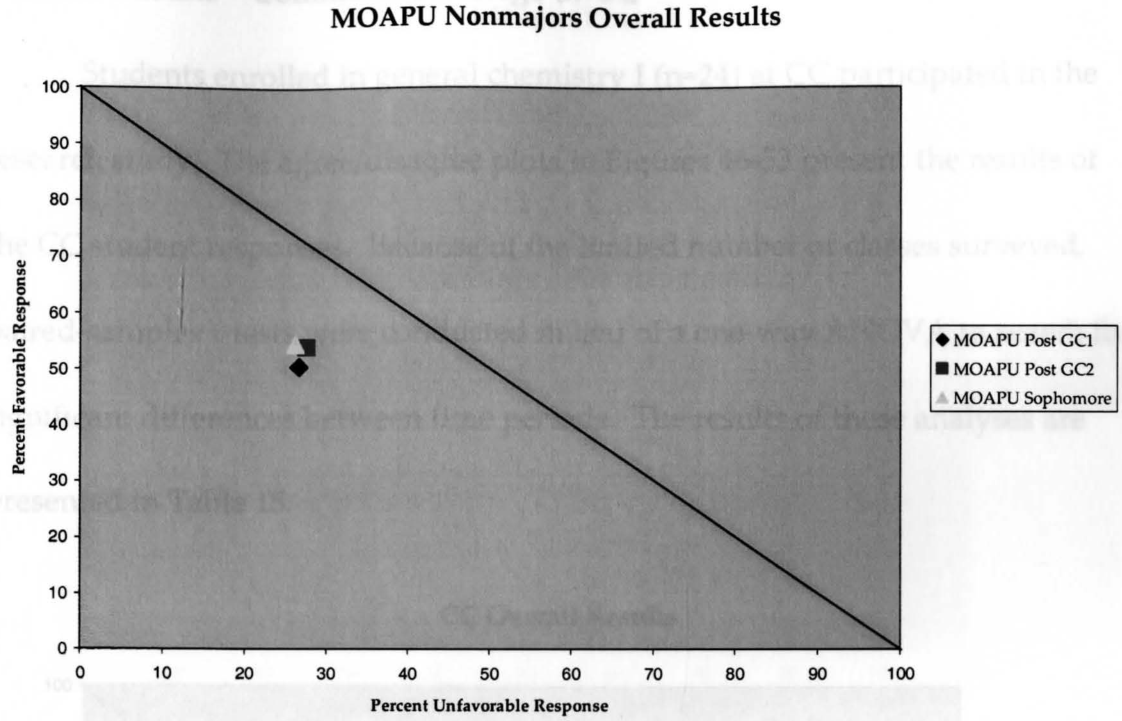


Figure 45. Agree/disagree plot of MOAPU non-chemistry majors, overall results.

Table 14. One-way ANOVA results of MOAPU student responses.

Cluster	p-value
Overall	0.825
Laboratory	0.403
Effort	0.728
Visualization	0.660
Concept	0.266
Math-link	0.663
Outcome	0.912
Reality-link	0.680

The ANOVA results in Table 14 show that in the context of this study, students at MOAPU do not improve significantly over the course of their undergraduate courses.

Student Results – Community College (n=24)

Students enrolled in general chemistry I (n=24) at CC participated in the research study. The agree/disagree plots in Figures 46-53 present the results of the CC student responses. Because of the limited number of classes surveyed, paired-samples t-tests were conducted in lieu of a one-way ANOVA to search for significant differences between time periods. The results of these analyses are presented in Table 15.

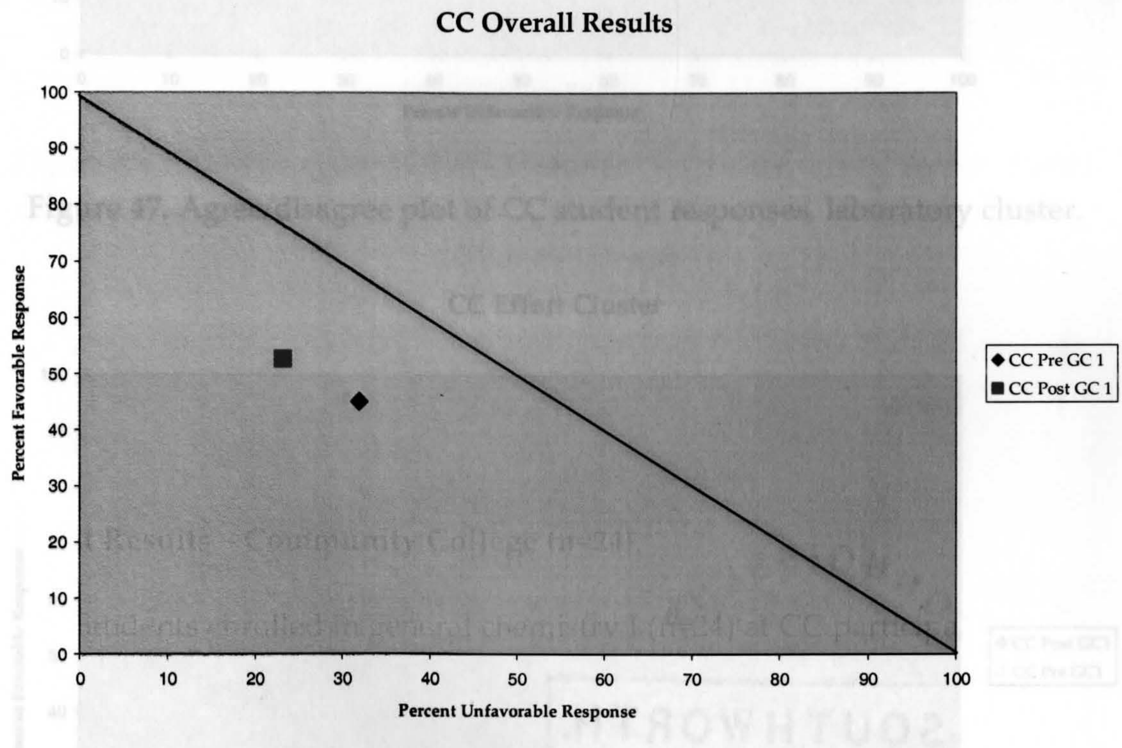


Figure 46. Agree/disagree plot of CC student responses, overall results.

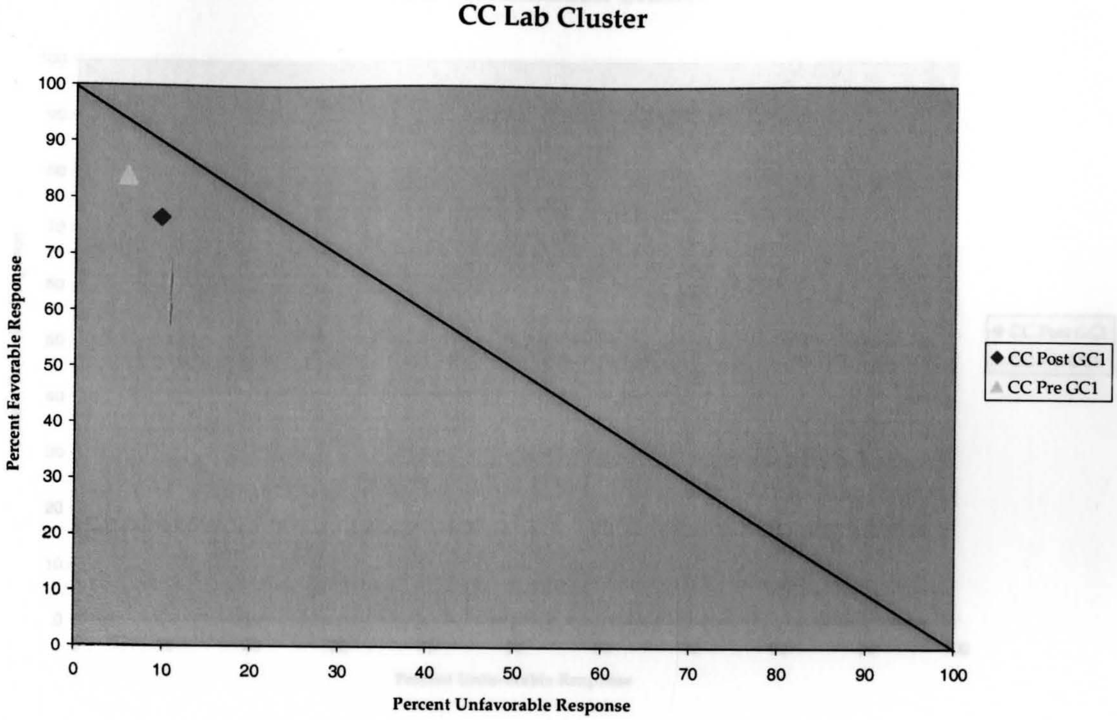


Figure 47. Agree/disagree plot of CC student responses, laboratory cluster.

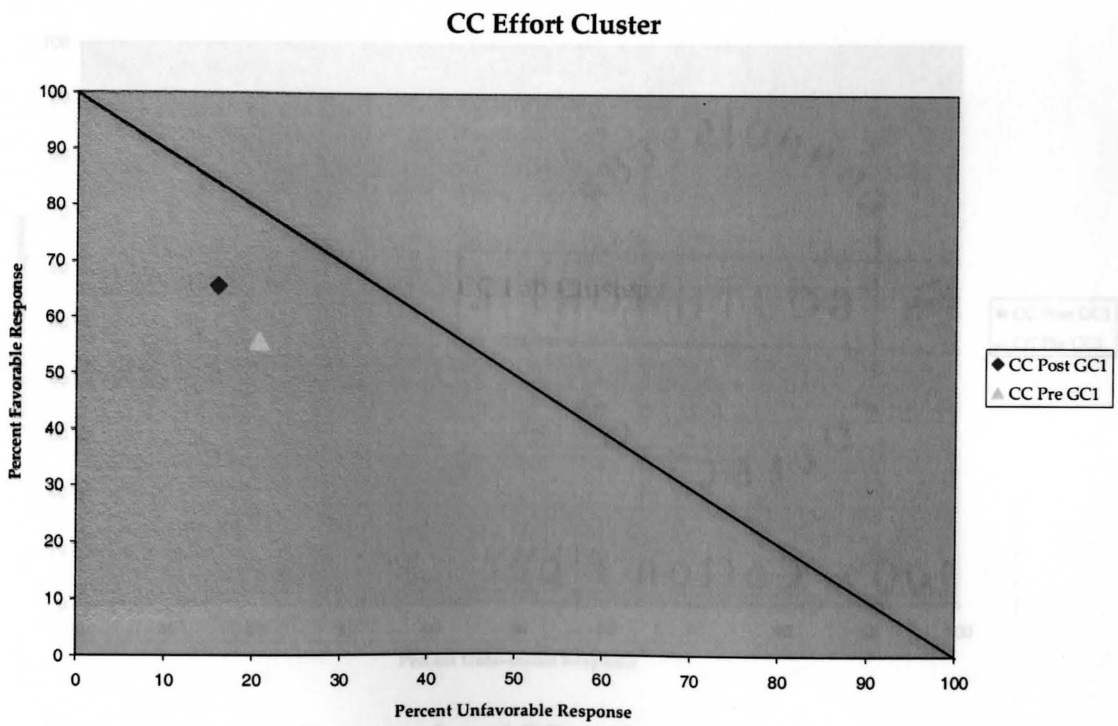


Figure 48. Agree/disagree plot of CC student responses, effort cluster.

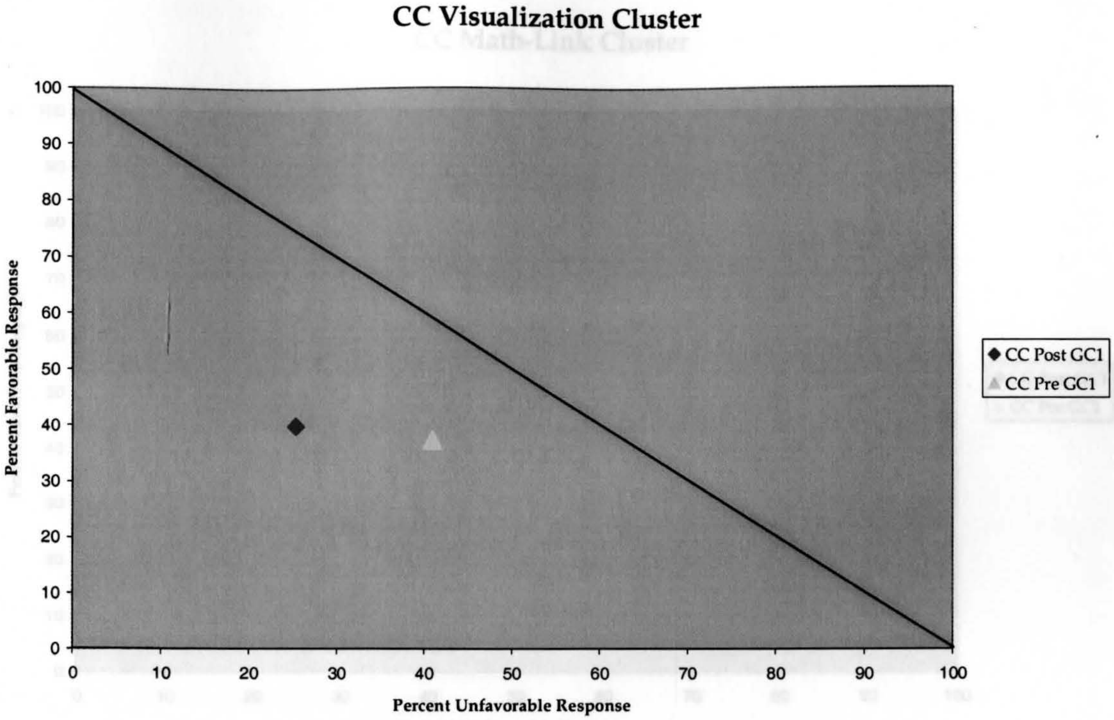


Figure 49. Agree/disagree plot of CC student responses, visualization cluster.

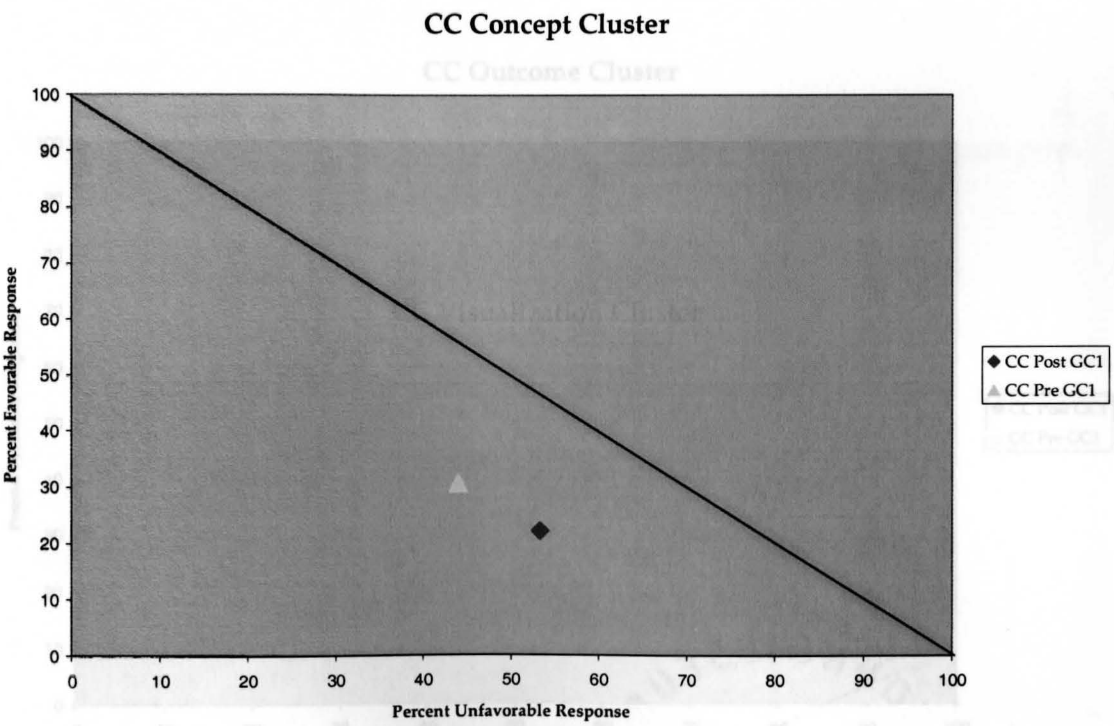


Figure 50. Agree/disagree plot of CC student responses, concept cluster.

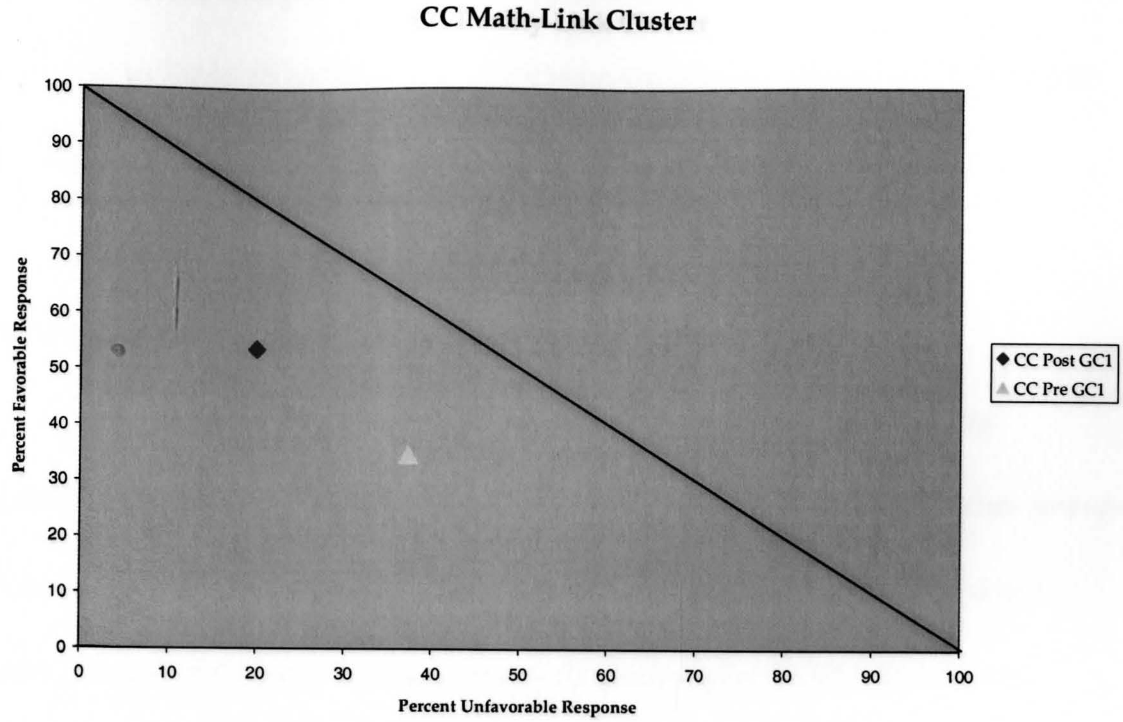


Figure 51. Agree/disagree plot of CC student responses, math-link cluster.

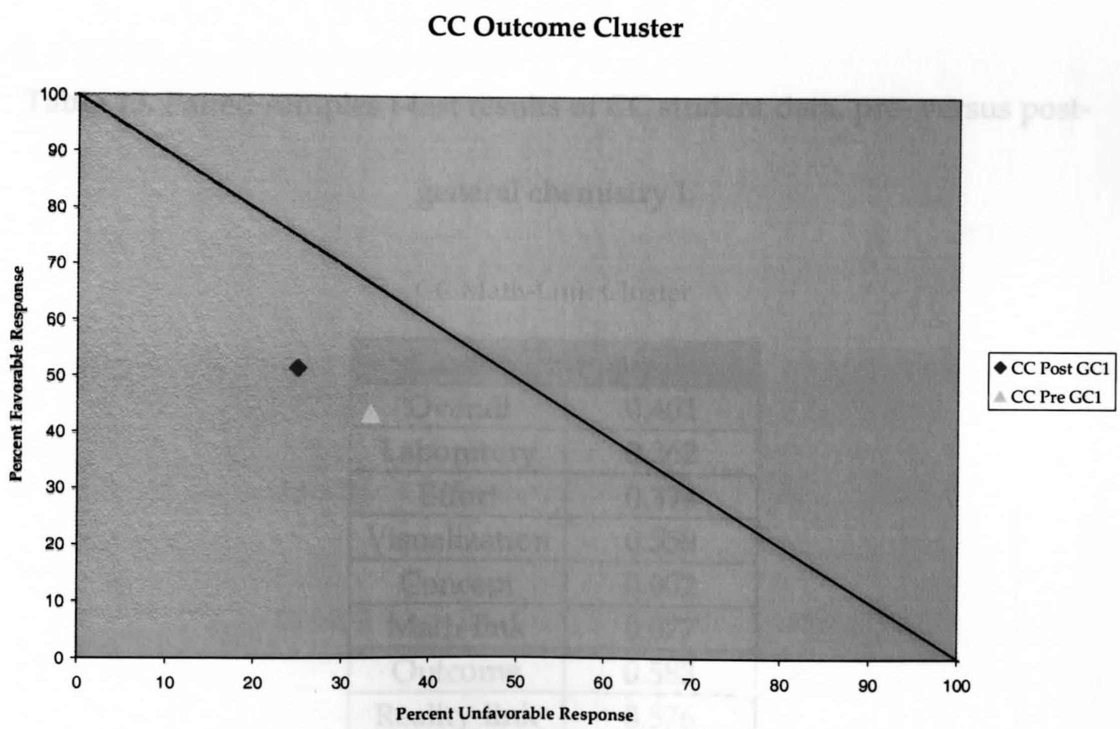


Figure 52. Agree/disagree plot of CC student responses, outcome cluster.

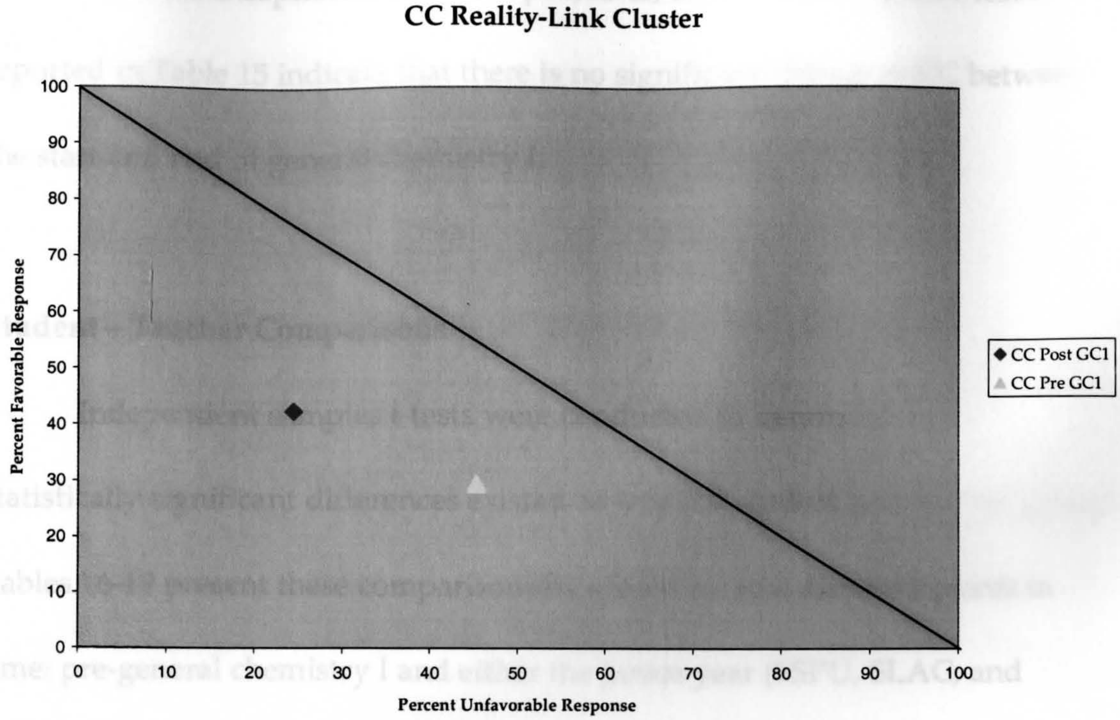


Figure 53. Agree/disagree plot of CC student responses, reality-link cluster.

Table 15. Paired-samples t-test results of CC student data, pre- versus post-general chemistry I.

Cluster	p-value
Overall	0.401
Laboratory	0.362
Effort	0.394
Visualization	0.559
Concept	0.002
Math-link	0.077
Outcome	0.583
Reality-link	0.576

With the exception of the concept cluster, the Paired-samples t-test results reported in Table 15 indicate that there is no significant change at CC between the start and end of general chemistry I.

Student – Teacher Comparisons

Independent samples t-tests were conducted to determine if any statistically significant differences existed among the student and teacher groups. Tables 16-19 present these comparisons by school for two different points in time: pre-general chemistry I and either the junior year (SSPU, SLAC, and MOAPU) or post-general chemistry I (CC). Any student-teacher differences that were determined to be significant are indicated by a "yes" followed by the p-value for that particular comparison.

Table 16. Independent samples t-test results of SSPU student-teacher comparisons.

Cluster	Pre-GCI	Junior
Overall	Yes, p<0.001	No
Laboratory	Yes, p<0.001	No
Effort	Yes, p<0.001	No
Visualization	Yes, p<0.001	No
Concept	Yes, p<0.001	Yes, p=0.005
Math-link	Yes, p<0.001	No
Outcome	Yes, p<0.001	No
Reality-link	Yes, p<0.001	No

Table 17. Independent samples t-test results of SLAC student-teacher comparisons.

Cluster	Pre-GCI	Junior
Overall	Yes, p=0.001	No
Laboratory	No	No
Effort	Yes, p=0.012	No
Visualization	Yes, p<0.001	No
Concept	Yes, p<0.001	No
Math-link	Yes, p=0.015	No
Outcome	Yes, p=0.017	Yes, p=0.049
Reality-link	Yes, p<0.001	No

Table 18. Independent samples t-test results of MOAPU student-teacher comparisons.

Cluster	Pre-GCI	Junior
Overall	Yes, p<0.001	No
Laboratory	Yes, p<0.001	No
Effort	Yes, p<0.001	No
Visualization	Yes, p<0.001	No
Concept	Yes, p<0.001	No
Math-link	Yes, p<0.001	No
Outcome	Yes, p<0.001	No
Reality-link	Yes, p<0.001	No

Table 19. Independent samples t-test results of CC student-teacher comparisons.

Cluster	Pre-GCI	Post-GCI
Overall	Yes, $p<0.001$	No
Laboratory	Yes, $p<0.001$	No
Effort	Yes, $p<0.001$	No
Visualization	Yes, $p<0.001$	No
Concept	Yes, $p<0.001$	No
Math-link	Yes, $p<0.001$	Yes, $p=0.002$
Outcome	Yes, $p<0.001$	No
Reality-link	Yes, $p<0.001$	No

The independent samples t-test results at the four universities all exhibit a similar pattern: at the beginning general chemistry I, statistically significant differences exist between student and teacher. By the end of either the junior year or general chemistry I, these differences have mostly disappeared.

Chapter 5. Conclusions

It is the purpose of this chapter to explore the significance of the data presented in Chapter 4. Specifically, the improvements seen in reliability and validity of the CHEMX Survey as compared to the MPEX Survey will be discussed, as will answers to the research questions identified earlier in this work:

1. How do the expectations that faculty members have for their students compare across the different disciplines of chemistry?
2. How do student expectations for learning chemistry change as they progress through an ACS approved undergraduate degree in chemistry?
3. How do student expectations for learning chemistry compare to those of their instructors?

This chapter will also discuss directions for future research in consideration of the findings of this inquiry.

Reliability and Validity of CHEMX

When conducting survey research, the reliability and validity of the instrument is of the utmost importance. Despite this, the research which resulted in MPEX neglected these important facets of survey research. As can be seen in

Table 2, none of the six clusters in their original forms can be considered reliable as the individual Cronbach alpha values are less than 0.7. In addition, the factor analyses that were performed on MPEX showed evidence for three or four clusters of statements – not the six the researchers reported in the literature. Despite the lack of evidence to support the choice of MPEX clusters or the reliability of individual items, MPEX was published in a peer-reviewed journal and continues to be used in physics education research.

Given the questionable reliability of MPEX, it was critical for this research to carefully analyze the data in support of individual item reliability as well as cluster formation. Clearly, the inter-item correlations and factor analyses provided evidence for the greatly improved reliability of the instrument as indicated by the Cronbach alpha values reported in Table 2.

No statistical analyses exist to test the validity of an instrument. Thus, evidence of validity must be gathered from other sources. For this study, interviews were conducted with three university chemistry professors as well as six students who were enrolled in general chemistry II and had taken the CHEMX Survey the previous semester in general chemistry I. Since the MPEX researchers conducted extensive interviews to establish the validity of the MPEX Survey, it was only necessary to ascertain the validity of the original statements that were new to CHEMX. Such interviews explored explanations as to why faculty and students selected their responses, indicating that they had read and interpreted the statements in a manner consistent with the intent of this research. Further evidence for the validity of the CHEMX Survey will be presented in subsequent portions of this chapter.

Research Question 1. How do the expectations that faculty members have for their students compare across the different disciplines of chemistry?

The t-test results in Tables 4-11 show that chemistry education researchers score significantly higher than their counterparts in the other disciplines of chemistry. These results are consistent with the belief that individuals who closely study aspects of student learning should score higher on an instrument created to measure dimensions of that learning. Looking at all disciplines except chemistry education, however, there are few significant differences among faculty of the other five traditional disciplines of chemistry. In fact, Tables 4-11 show that of the approximately 125 comparisons made, there are only two significant, non-chemistry education differences: math-link cluster results of analytical chemists versus physical chemists and visualization cluster results of analytical chemists versus organic chemists. In both cases, these differences are plausible and lend further credence to the validity of the instrument.

The purpose of the statements contained within the math-link cluster is to explore the beliefs that teachers and learners of chemistry have about the role that mathematics plays in the discipline. Calculations performed by analytical chemists and taught in most analytical chemistry courses typically are "plug and chug" type calculations. In contrast, the mathematics encountered in physical chemistry tend to be more conceptually complex. Even a simplistic physical chemistry expression can contain complex terms. For example, knowing that "$\hat{H}$" represents a Hamiltonian operator is of little help if a student does not know what a Hamiltonian operator is. The same cannot be said of most terms in an analytical chemistry expression where students can perform calculations without a deep understanding of the material from which the equation is derived. It is not surprising, therefore, to find differences in expectations between physical and analytical chemists with regard to mathematics.

Of the traditional chemistry disciplines, organic chemists have spent the most time and effort utilizing and promoting visualization. In fact, the course of organic chemistry was changed forever in 1828 when Friedrich Wöhler synthesized urea from cyanic acid and ammonia. It was never his intent to deal a death-blow to vitalism but merely to continue his study of the stereochemistry of cyanates. On the other hand, analytical chemists typically place little emphasis on this skill as it has little relation to the work that most of them routinely do. In short, organic chemists have been concerned with the three-dimensional shapes of molecules for well over two hundred years and it is only natural that the expectations that they have for their students in this regard should be significantly higher.

Research Question 2. How do student expectations for learning chemistry change as they progress through an ACS approved undergraduate degree in chemistry?

Overall, pre-general chemistry I results presented in Figures 18, 26, 36, and 46 indicate a positive correlation between a student's performance on CHEMX and the selectivity of their undergraduate institution. SLAC students scored higher than both MOAPU and SSPU students who in turn scored higher than CC students. These results provide further evidence to support the validity of the CHEMX Survey.

The post-general chemistry I results show that few significant changes occurred during the semester. On the one hand, these results are not surprising since fifteen weeks is a relatively short period of time in which to promote change; however, these results are quite discouraging as well, as they show that chemists make little progress in changin students' expectations regarding these important dimensions of learning chemistry. Although it would appear that there is a sizable change in expectations at CC as indicated by the agree/disagree plots found in Figures 46-53, the t-test results included in Table 15 show that the changes are not significant. This is most likely an artifact of the small sample size as it becomes increasingly difficult to show significant differences with smaller samples.

One of the more interesting trends in the student data is the large decline in expectations that occurs sometime during the second semester of general chemistry at SLAC and MOAPU (data for this time period is not available for SSPU). What is it about general chemistry II that causes such a steep drop? This important question is difficult to answer with the data collected in this study because as the agree/disagree plots in Figures 27-33 and 37-43 show, there are similar declines in expectations across most of the clusters. One possible explanation focuses on the material covered 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 fact, nearly half of the course concentrates on chemical equilibrium and since most types of equilibrium can be mathematically described with variants of the same equation, the course can become monotonous. In such a heavily mathematical environment, it also becomes easy for students to lose sight of the underlying chemical concepts and focus exclusively on the equations.[38-40] For many students, the material covered holds little relevance for their chosen professions. Simultaneously, the laboratory which provided an alternative to the monotony of lecture becomes a weekly exercise in titrations or qualitative analysis. It is not surprising that CHEMX measures a precipitous drop in cognitive expectations during the second semester of general chemistry.

The agree/disagree plots in Figures 18-25, 27-33, and 37-43 show that students' expectations improve slightly during organic chemistry, and, by the time students have finished their junior year, they have mostly recovered from the previously noted declines. To determine whether any of the differences across time periods were significant, ANOVAs were performed. The results of these analyses are included in Tables 12-14. Of the ANOVAs conducted, only those at SSPU (Table 12) show any significant improvements from beginning to end; those at SLAC and MOAPU, Tables 13 and 14 respectively, show no significant improvement. It is important to point out, however, that the junior sample size at MOAPU limits the ability to draw conclusions with certainty.

What is not evident from the agree/disagree plots noted above, are the reasons for the increases. Do expectations increase because the students are beginning to mature and to think more like professional chemists? Or, do expectations improve because most of the struggling students have been "weeded out" by the end of the sophomore year? To answer these question, agree/disagree plots (Figures 34-35 and 44-45) were generated to separate SLAC and MOAPU students into chemistry/biochemistry majors and non-chemistry majors. Data analysis reveals an increase in cognitive expectations among chemistry and biochemistry majors at both schools similar to the patterns seen in the overall results for all students in the study. However, there is little change among non-chemistry majors at MOAPU and large decreases among non-chemistry majors at SLAC. Non-chemistry majors at MOAPU are all science, technology, engineering, and mathematics majors while those at SLAC contain a significant number of students that Sheila Tobias would consider members of the second tier[37] – English literature, history, business, and even a Spanish language major.

It is clear from these plots that little has changed in the course of the 15 years since the publication of *They're Not Dumb, They're Different*. Teachers of introductory chemistry courses have structured their courses in such a way as to unfortunately discourage some students from pursuing future study in chemistry. Beyond this, however, it is apparent from the agree/disagree plots of the chemistry majors that these same instructors are also discouraging many of the students with intentions of pursuing careers in chemistry from ever completing their degrees. In short, it would appear from the data collected that some students who eventually do become chemists do so in spite of the way chemistry is taught. If chemists hope to attract more students to the discipline, there must be a close examination of novice learners and their introductory chemistry experiences. CHEMX provides an easy-to-use tool for chemists to "take the cognitive temperature" of these students.

Research Question 3. How do student expectations for learning chemistry compare to those of their instructors?

As stated previously in this work, large differences in cognitive expectations between students and their instructor can cause difficulties in learning. In order to determine if any statistically significant differences existed between these groups, independent samples t-tests were conducted at each institution (pre-general chemistry I versus post-general chemistry II at CC and pre-general chemistry I versus completion of the junior year at SSPU, SLAC, and MOAPU). The results of these analyses are included in Tables 16-19. With the exception of the laboratory cluster at SLAC, the results show that statistically significant differences exist between the students and faculty at all four institutions for all clusters at the beginning of general chemistry I. By and large, these differences have disappeared by the end of the junior year. It is important to note that the seemingly large improvement in cognitive expectations at CC is a function of the small sample size and not an actual change.

Summary of Findings

The cognitive expectations that students have for learning are an important component of their success in chemistry. This research has resulted in the development of CHEMX - a valid, reliable, and easy-to-use means for chemists to measure these cognitive expectations. CHEMX was used in four undergraduate institutions to explore how cognitive expectations changed as students proceeded through the chemistry courses required of an ACS approved undergraduate degree. Results show that students change very little during general chemistry I but undergo a period of expectational decline during the second semester of general chemistry. Students slowly reverse this downward trend in the sophomore and junior years. The results also indicate a substantial difference in how chemistry and biochemistry majors score on CHEMX versus non-chemistry majors.

Future Research

As is the case with most research, there are as many questions answered as there are new ones uncovered – this is certainly the case in the present study. The biggest unanswered questions mostly seem to focus around the large decrease in cognitive expectations that occurs during the second semester of general chemistry. Though this researcher has offered one explanation for the decrease, it is merely a hypothesis worth further study. It would be important, therefore, to conduct an in-depth study of this crucial period in the cognitive development of the students enrolled in chemistry courses in an effort to better understand this decline. More importantly, such research must not only understand the cognitive processes, but reveal mechanisms to help students cross this chasm, as it is clear that traditional instruction is not conducive to doing so for either chemistry or non-chemistry majors. It would also be helpful to expand the study to include larger and more diverse student groups. In this way, it would be possible to determine if the steep decline seen during general chemistry II and the differences seen between chemistry majors and non-chemistry majors are widespread or particular to the subset of institutions in this study. It would also be important to have senior students about to graduate participate in the study in order to gain a complete picture of how cognitive expectations change over the course of an entire undergraduate chemistry degree.

References Cited

1. Gabel, D. *Journal of Chemical Education* **1999**, *76*, 548-554.

2. Abendroth, W.; Friedman, F. *Journal of Chemical Education* **1983**, *60*, 25-26.

3. Eddy, R. M. *Journal of Chemical Education* **2000**, *77*, 514-517.

4. Berdonosov, S. S.; Kuzmenko, N. E.; Kharisov, B. I. *Journal of Chemical Education* **1999**, *76*, 1086-1088.

5. Rowe, M. B. *Journal of Chemical Education* **1983**, *60*, 954-956.

6. Cardellini, L. *Journal of Chemical Education* **2000**, *77*, 1571-1573.

7. Redish, E. F.; Saul, J. M. *American Journal of Physics* **1998**, *66*, 212-224.

8. Ausubel, D. P. *Education Psychology: A Cognitive View* Holt, Rinehart, and Winston: New York, 1968.

9. Novak, J. D. *A Theory of Education* Cornell University: Ithaca, 1977

10. Johnstone, A. H. *Journal of Chemical Education* **1997**, *74*, 262-268.

11. Nakhleh, M. B. *Journal of Chemical Education* **1992**, *69*, 191-196.

12. Mulford, D. R.; Robinson, W. R. *Journal of Chemical Education* **2002**, *79*, 739-744.

13. Driver, R.; Easley, J. *Studies in Science Education* **1978**, *5*, 61-84.

14. Driver, R. *Studies in Science Education* **1983**, *10*, 37-60.

15. Treagust, D. F. *International Journal of Science Education* **1988**, *10*, 159-169.

16. Bodner, G. M. *Journal of Chemical Education* **1991**, *68*, 385-388.

17. Galley, W. C. *Journal of Chemical Education* **2004**, *81*, 523-525.

18. Perry, W. G., Jr. *Forms of Intellectual and Ethical Development in the College Years: A Scheme* Holt, Rinehart, and Winston: New York, 1979.

19. Finster, D. C. *Journal of Chemical Education* **1989**, *66*, 8, 659-661.

20. Baxter-Magolda, M.; Porterfield, W. *Journal of College Student Personals* **1985**, *26*, 343-351.

21. Finster, D. C. *Journal of Chemical Education* **1991**, *68*, 748-756.

22. Johnstone, A. H. *Journal of Computer Assisted Learning* **1991**, *7*, 75-81.

23. Atkinson, R. C. Supply and Demand for Scientists and Engineers: A National Crisis in the Making. Presented at AAAS National Meeting, New Orleans, February 18, 1990.

24. Tobias, S. *They're Not Dumb, They're Different: Stalking the Second Tier* Research Corporation: Tucson, 1990.

25. Saul, J. M. Ph.D. Dissertation, University of Maryland, 1998.

26. Fraenkel, J. R.; Wallen, N. E. *How to Design and Evaluate Research in Education* McGraw Hill: Boston, 2003.

27. Osborne, C. E. *Journal of Chemical Education* **1924**, *1*, 104-109.

28. Mason, D. S. *Journal of Chemical Education* **2004**, *81*, 1081.

29. Tai, R. H.; Sadler, P. M.; Loehr, J. F. *Journal of Research in Science Teaching* **2005**, *46*.

30. Ricci, R. W.; Ditzler, M. A. *Journal of Chemical Education* **1991**, *68*, 228-231.

31. Wu, H. W.; Shah, P. *Science Education* **2004**, *88*, 465-492.

32. Wu, H. W.; Krajcik, J. S.; Soloway, E. *Journal of Research in Science Teaching,* **2001**, *38*, 821-842.

33. Mathewson, J. H. *Science Education* **1999**, *83*, 33-54.

34. Fennema, E.; Leder, G. C. *Mathematics and Gender* Teacher College Press: New York, 1990.

35. American Chemical Society: Committee on Professional Development. http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education \cpt\programs.html (last accessed October 11, 2004).

36. Farrell, J. J.; Moog, R. S.; Spencer, J. N. *Journal of Chemical Education* **1999**, *76*, 570-574.

37. Women, Minorities, and Persons with Disabilities in Science and Engineering: National Science Foundation. http://www.nsf.gov/statistics/ pubseri.cfm?TopID=14&SubID=45&SeriID=6#recentpub (last accessed July 1, 2005).

38. Nurrenbern, S. C.; Pickering, M. *Journal of Chemical Education* **1987**, *64*, 508-510.

39. Sawrey, B. A. *Journal of Chemical Education* **1990**, *67*, 248-252.

40. Nakhleh, M. B. *Journal of Chemical Education* **1993**, *71*, 52-55.

Appendix A. Human Subjects Review Committee Approvals

[illegible] State University / One University Plaza [illegible]

[illegible]

February 10, 2005

Dr. Stacey Lowery Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC Protocol Number [illegible]
Title: Assessing Cognitive Expectations for Learning Chemistry

Dear Dr. Bretz and Mr. Grove

The Human Subjects Research Committee has reviewed the abovementioned protocol and determined that it is exempt from full committee review based on a DHHS Category 1 exemption.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

The HSRC would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies
Research Compliance Officer

PJK/sc

c: Dr. Daryl Mincey, Chair
Department of Chemistry

www.ysu.edu

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
Dean of Graduate Studies and Research
330-941-3091
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E-Mail: graduateschool@cc.ysu.edu

February 10, 2005

Dr. Stacey Lowery Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC Protocol Number: 62-2005
Title: Assessing Cognitive Expectations for Learning Chemistry

Dear Dr. Bretz and Mr. Grove:

The Human Subjects Research Committee has reviewed the abovementioned protocol and determined that it is exempt from full committee review based on a DHHS Category 3 exemption.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

The HSRC would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies
Research Compliance Officer

PJK/cc

c: Dr. Daryl Mincey, Chair
Department of Chemistry

www.ysu.edu

TO PIs: complete items, print out then sign.

Youngstown State University
Human Subjects Research Committee

Exempt Protocol Summary Form

(To be completed by Human Subjects Secretary.)

Date Submitted	Protocol Number

Title of Research Project: CHEMX: Assessing Cognitive Expectations for Learning Chemistry

Principal Investigator/Faculty Advisor (include)	Department	Phone	Email address
Dr. Stacey Lowery Bretz	Chemistry	x7112	slbretz@ysu.edu

Co-investigator/Student Investigator	Department	Phone	Email address
Nathaniel Grove	Chemistry	x1562	nategrove@hotmail.com

Co-investigator/Student Investigator	Department	Phone	Email address

Anticipated Funding Source: NSF CCLI-ASA Grant No. R-125-003-6249

Projected Duration of Research: 24 months   Projected Starting Date: March 1, 2005

Other organizations and/or agencies, if any, involved in the study:

Exempt under code (see definitions on page one – check one) 1 ☐ 2 ☐ 3 ☑ 4 ☐ 5 ☐ 6 ☐

SUMMARY ABSTRACT: Please supply the following information below: BRIEF description of the participants, the location(s) of the project, the procedures to be used for data collection, whether data will be confidential or anonymous, disposition of the data, who will have access to the data. Attach copy of the Informed Consent Form and/or the measures (questionnaires) to be used in the project.

The heart of teaching and learning chemistry is the ability of the teacher to provide experiences that share a conceptually abstract, mathematically-rich subject with novice learners. This includes not only chemistry concepts, but also knowledge about how to learn chemistry. Students' expectations for learning chemistry in the university classroom impact their success in doing so.

Physics education research has explored the idea of student expectations with regards to learning physics, resulting in the development of MPEX (the Maryland Physics Expectation survey). We are adapting MPEX to develop a chemistry survey regarding student expectations for learning chemistry: CHEMX. In particular, CHEMX explores the role of laboratory and visualization in learning chemistry as shaped by Johnstone's work with the macroscopic, particulate, and symbolic representations of matter.

Data collection from university chemistry faculty and undergraduate students in chemistry programs approved by the ACS Committee on Professional Training will allow examination differences in expectations across the disciplines of chemistry. In order to access the validity of the survey, interviews will be conducted either individually or in small groups with both faculty and undergraduate students who have previously taken the survey (HSRC Protocol Nos. 05-2005 and 99-2004). Participation will be completely voluntary and will only occur with individuals who are 18 years or older. In order to encourage student respondents to participate, those having completed the interview will be given a gift certificate from the YSU Bookstore. All personally identifiable information collected will be kept strictly confidential. Only the principal and co-investigators will have access to this data.

Investigator/Advisor Signature   Date   Co-Investigator/Student Signature (if appropriate)   Date

☐ Approved ☐ Approved with Conditions ☐ Full Committee Review   HSRC Committee Chair   Date

YSU

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
Dean of Graduate Studies and Research
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E-Mail: graduateschool@cc.ysu.edu

August 23, 2004

Dr. Stacey Lowery Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC Protocol Number: 05-2005
Title: CHEMX: Assessing Cognitive Expectations for Learning Chemistry

Dear Dr. Bretz and Mr. Grove:

The Human Subjects Research Committee has reviewed the abovementioned protocol and determined that it is exempt from full committee review based on a DHHS Category 3 exemption.

Please note that your project is approved for one year. If your project extends beyond one year, you must submit a project Update form at that time.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

The HSRC would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies
Research Compliance Officer

PJK/cc

c: Dr. Daryl Mincey, Chair
Department of Chemistry

www.ysu.edu

__/__/__
Date Submitted

Youngstown State University
Human Subjects Research Committee

Exempt Protocol Summary Form

File Number

CHEMX: Assessing Cognitive Expectations for Learning Chemistry
Title of Research Project

Stacey Lowery Bretz | Chemistry | x7112 | slbretz@ysu.edu
Principal Investigator/Faculty Advisor | Department | Phone Extension | Email address

Nathaniel Grove | Chemistry | x1562 | nategrove@hotmai.
Co-investigator/Student Investigator | Department | Phone Number | Email address

Co-investigator/Student Investigator | Department | Phone Number | Email address

Co-investigator/Student Investigator | Department | Phone Number | Email address

Anticipated Funding Source NSF-CCLI Grant 12-125-C03-6249

Projected Duration of Research 24 months Projected Starting Date August 20, 2004

Other organizations and/or agencies, if any, involved in the study

Exempt under code (see definitions on page one – circle one) 1 2 3 4 5 6

SUMMARY ABSTRACT: Please supply the following information below: BRIEF description of the participants, the location(s) of the project, the procedures to be used for data collection, whether data will be confidential or anonymous, disposition of the data, who will have access to the data. Attach copy of the Informed Consent Form and/or the measures (questionnaires) to be used in the project.

The heart of teaching and learning chemistry is the ability of the teacher to provide experiences that share a conceptually abstract, mathematically-rich subject with novice learners. This includes not only chemistry concepts, but also knowledge about how to learn chemistry. Students' expectations for learning chemistry in the university classroom impact their success in doing so.

Physics education research has explored the idea of student expectations with regard to learning physics, resulting in the development of MPEX (the Maryland Physics Expectation survey). We are adapting MPEX to develop a chemistry survey regarding student expectations for learning chemistry: CHEMX. In particular, CHEMX explores the role of laboratory and visualization in learning chemistry as shaped by Johnstone's work with the macroscopic, particulate, and symbolic representations of matter.

Data collection from university chemistry faculty, undergraduates and graduate students in chemistry programs approved by the ACS Committee on Professional Training will allow examination of differences in expectations across the disciplines of chemistry. This online survey will be given to undergraduate students in a number of educational settings that include both private and public universities and colleges. Students will be surveyed twice during the course of the next academic year: once during the first week of classes of the fall semester/quarter, the second during the last week of the spring semester/quarter. CHEMX will be given as a required assignment for all students to complete. In the event that the student is under the age of 18, a comparable assignment will be given. All personally identifiable information collected will be kept strictly confidential. Only the principal and co-investigator will have access to the data.

__________ __/__/__
Investigator/Advisor Signature Date

__________ __/__/__
Co-Investigator/Student Signature (if appropriate) Date

☐ Approved ☐ Approved with Conditions ☐ Full Committee Review

__________ __/__/__
HSRC Committee Chair Date

YSU

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
Dean of Graduate Studies and Research
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E-Mail: graduateschool@cc.ysu.edu

April 13, 2004

Dr. Stacey Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC PROTOCOL NUMBER: 99-2004
TITLE: CHEMX: Assessing Cognitive Expectations for Learning Chemistry

Dear Dr. Bretz and Mr. Grove:

The Human Subjects Research Committee has reviewed the abovementioned protocol and determined that it is exempt from full committee review based on a DHHS Category 2 exemption.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

The HSRC would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies and Research
Research Compliance Officer

PJK/cc

c: Dr. Timothy Wagner, Acting Chair
Department of Chemistry

www.ysu.edu

___/___/___
Date Submitted

Youngstown State University
Human Subjects Research Committee

File Number

Exempt Protocol Summary Form

CHEMX: Assessing Cognitive Expectations for Learning Chemistry
Title of Research Project

Stacey Lowery Bretz | Chemistry | 7112 | slbretz@ysu.edu
Principal Investigator/Faculty Advisor | Department | Phone Extension | Email address

Nathaniel Grove | Chemistry | 1562 | nategrove@hotmail.com
Co-investigator/Student Investigator | Department | Phone Number | Email address

Co-investigator/Student Investigator | Department | Phone Number | Email address

Co-investigator/Student Investigator | Department | Phone Number | Email address

Anticipated Funding Source NSF - CCLI - ASA - 0404975

Projected Duration of Research 15 months Projected Starting Date May 1, 2004

Other organizations and/or agencies, if any, involved in the study

Exempt under code (see definitions on page one – circle one) 1 2 3 4 5 6

SUMMARY ABSTRACT: Please supply the following information below: BRIEF description of the participants, the location(s) of the project, the procedures to be used for data collection, whether data will be confidential or anonymous, disposition of the data, who will have access to the data. Attach copy of the Informed Consent Form and/or the measures (questionnaires) to be used in the project.

The heart of teaching and learning chemistry is the ability of the teacher to provide experiences that share a conceptually abstract, mathematically-rich subject with novice learners. This includes not only chemistry concepts, but also knowledge about how to learn chemistry. Students' expectations for learning chemistry in the university classroom impact their success in doing so.

Physics education research has explored the idea of student expectations with regard to learning physics, resulting in the development of MPEX (the Maryland Physics Expectation survey). We are adapting MPEX to develop a chemistry survey regarding student expectations for learning chemistry: CHEMX. In particular, CHEMX explores the role of laboratory in learning chemistry as shaped by Johnstone's work with the macroscopic, particulate, and symbolic representations of matter.

Data collection from university chemistry faculty in chemistry programs approved by the ACS Committee on Professional Training will allow examination of differences across the disciplines of chemistry. The survey will be pilot-tested on faculty members of the chemistry department at a large state university (e.g. Ohio State University) to assess its validity and reliability. After pilot-testing is completed, university chemistry faculty from across the country will be surveyed. Approximately 750 faculty members will be surveyed at 50 universities randomly sampled across ACS approved programs. Data collection, including informed consent, will be done using an Internet version of the CHEMX survey; this will expedite data analysis and minimize data entry error given the large N. Though a complete list of all faculty members who are sent a survey will be maintained, the survey results will be kept confidential. Only the principal investigator and co-investigator will have access to this data.

Stacey Lowery Bretz 4/9/04
Investigator/Advisor Signature Date

Nathaniel Grove 4/9/2004
Co-Investigator/Student Signature (if appropriate) Date

☐ Approved ☐ Approved with Conditions ☐ Full Committee Review

HSRC Committee Chair ___/___/___ Date

YSU

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
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June 17, 2003

Dr. Stacey Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: Human Subjects Research Protocol #85-2003

Dear Dr. Bretz and Mr. Grove:

The Human Subjects Research Committee of Youngstown State University has reviewed the protocol you submitted, Protocol #85-2003, "Expectations for Learning University Chemistry," and has determined it is exempt from full committee review based on a DHHS Category 2 exemption, *but with the following condition:*

> *(1) the Investigator should ensure that students not participating will not be able to be identified;*

Please submit the aforementioned materials to Cheryl Coy, Secretary, Office of Grants and Sponsored Programs, 357 Tod Hall, before initiating your project.

Any changes in your research activity should be promptly reported to the Human Subjects Review Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

Sincerely,

Peter J. Kasvinsky
Dean of Graduate Studies
Research Compliance Officer

PJK:cc

C: Dr. Daryl Mincey, Chair
Department of Chemistry

www.ysu.edu

YSU

Youngstown State University / One University Plaza / Youngstown, Ohio 44555-0001
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June 19, 2003

Dr. Stacey Bretz, Principal Investigator
Mr. Nathaniel Grove, Co-investigator
Department of Chemistry
UNIVERSITY

RE: HSRC Protocol #85-2003

Dear Dr. Bretz and Mr. Grove:

The Human Subjects Research Committee of Youngstown State University has reviewed your response to their concerns regarding the aforementioned protocol titled "Expectations for Learning University Chemistry." The Committee has reviewed the modifications you provided and determined that your protocol now fully meets YSU Human Subjects Research guidelines. Therefore, I am pleased to inform you that your project has been fully approved.

Any changes in your research activity should be promptly reported to the Human Subjects Research Committee and may not be initiated without HSRC approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the Human Subjects Research Committee.

We wish you well in your study.

Sincerely,

Peter J. Kasvinsky
Dean, School of Graduate Studies
Research Compliance Officer

PJK:cc

c: Dr. Daryl Mincey, Chair
Department of Chemistry

www.ysu.edu

Exempt Protocol Submission Form

Date Submitted ____/____/____ File Number ____

Title of Research Project Expectations for Learning University Chemistry

Principal Investigator(s) Nathaniel Grove

Advisor (if appropriate) Stacey Lowery Bretz

Department(s) Chemistry

Anticipated Funding Source FIPSE grant - R 276 003 6250

Projected Duration of Research 3 months Projected Starting Date May 1, 2003

Other organizations and/or agencies, if any, involved in the study ____

Exempt under code (see definitions on reverse side – circle one) 1 (2) 3 4 5 6

Summary Abstract (BRIEF description of participants, measures, procedures used in the proposed research - 250 words or less)

Attach copy of ☑ Consent Form and/or ☑ measures)

The goal of this research project is to explore the expectations for learning chemistry in a university general chemistry classroom. We will administer a modified version of the MPEX, Maryland Physics Expectations survey, that reflects the differences between physics and chemistry as a discipline. Respondents will be asked to read a series of statements about learning chemistry and to rate their level of agreement or disagreement with a particular statement. The modified survey will be pilot – tested on undergraduate chemistry research students to assess its validity and reliability. As we are particularly interested in the expectations of entering university students, we intend to give this survey to incoming NEOUCOM students. Also of interest are any differences in expectations between such recent high school graduates and the expectations of their teachers, i.e., high school chemistry teachers. Accordingly, the survey will also be given to area high school teachers who are participating in summer research experiences in the chemistry department.

Nathaniel Grove 6/9/03
Investigator's Signature Date

Stacey Lowery Bretz 6/9/03
Advisor's Signature (if appropriate) Date

☐ Approved ☐ Approved with Conditions ☐ Full Committee Review

____ HSRC Committee Chair ____/____/____ Date

Appendix B. The CHEMX Survey

Below are 47 statements which may or may not describe your beliefs about learning chemistry. You are asked to rate each statement by choosing a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree   2: Disagree   3: Neutral   4: Agree   5: Strongly Agree

Answer the questions by choosing the number that best expresses your feeling. Work quickly. Do not over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you do not understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

1.	I can do well in the chemistry laboratory (C grade or better) without understanding the chemical principles behind the labs.	1 2 3 4 5
2.	I go over my class notes carefully to prepare for tests in this course.	1 2 3 4 5
3.	When I see a drawing of a molecule in my textbook, I try to imagine what it might look like in 3-D.	1 2 3 4 5
4.	Problem solving in chemistry means matching problems with facts or equations and then substituting values to get a number.	1 2 3 4 5
5.	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	1 2 3 4 5
6.	There is very little that I can do to test whether an answer I calculate is right (besides looking the answer up in the back of the book).	1 2 3 4 5
7.	Learning chemistry made me change some of my ideas about how the physical world works.	1 2 3 4 5
8.	I read the text in detail and work through many of the examples given there.	1 2 3 4 5
9.	In this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens.	1 2 3 4 5
10.	When I see a chemical formula, I try to picture its structure.	1 2 3 4 5
11.	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	1 2 3 4 5
12.	It really doesn't matter how hard I work in the laboratory; the most important thing is to get the right answer.	1 2 3 4 5
13.	It is important that I learn proper laboratory techniques in this course.	1 2 3 4 5
14.	Chemical theories have little relation to what I experience in the real world.	1 2 3 4 5
15.	A good understanding of chemistry is necessary for me to achieve my career goals. A good grade in this course is not enough.	1 2 3 4 5

CHEMX: Assessing Cognitive Expectations for Learning Chemistry

Below are 47 statements which may or may not describe your beliefs about learning chemistry. You are asked to rate each statement by choosing a number between 1 and 5 where the numbers mean the following:

1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree

Answer the questions by choosing the number that best expresses your feeling. Work quickly. Do not over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you do not understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

1.	I can do well in the chemistry laboratory (C grade or better) without understanding the chemical principles behind the labs.	1 2 3 4 5
2.	I go over my class notes carefully to prepare for tests in this course.	1 2 3 4 5
3.	When I see a drawing of a molecule in my textbook, I try to imagine what it might look like in 3-D.	1 2 3 4 5
4.	Problem solving in chemistry means matching problems with facts or equations and then substituting values to get a number.	1 2 3 4 5
5.	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	1 2 3 4 5
6.	There is very little that I can do to test whether an answer I calculate is right (besides looking the answer up in the back of the book).	1 2 3 4 5
7.	Learning chemistry made me change some of my ideas about how the physical world works.	1 2 3 4 5
8.	I read the text in detail and work through many of the examples given there.	1 2 3 4 5
9.	In this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens.	1 2 3 4 5
10.	When I see a chemical formula, I try to picture its structure.	1 2 3 4 5
11.	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	1 2 3 4 5
12.	It really doesn't matter how hard I work in the laboratory; the most important thing is to get the right answer.	1 2 3 4 5
13.	It is important that I learn proper laboratory techniques in this course.	1 2 3 4 5
14.	Chemical theories have little relation to what I experience in the real world.	1 2 3 4 5
15.	A good understanding of chemistry is necessary for me to achieve my career goals. A good grade in this course is not enough.	1 2 3 4 5

	1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree	
16.	Knowledge in chemistry consists of many pieces of information, each of which applies primarily to a specific situation.	1 2 3 4 5
17.	My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it.	1 2 3 4 5
18.	I don't spend much time constructing 3-D models of the 2-D structures that I draw in my class notes or read in my textbook.	1 2 3 4 5
19.	In doing a chemistry problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	1 2 3 4 5
20.	When I do an experiment in the laboratory, I try to picture the chemistry that is happening.	1 2 3 4 5
21.	The derivations or proofs of equations in class or in the text have little to do with solving problems or with the skills I need to succeed in this course.	1 2 3 4 5
22.	After I numerically solve a chemistry problem, I check my answer to see if the answer makes sense.	1 2 3 4 5
23.	I really don't expect to understand how laboratory instruments work – they are just tools that help me complete the lab.	1 2 3 4 5
24.	Solving a chemistry problem may require me to be able to draw molecules in more than one way.	1 2 3 4 5
25.	Only a very few specially qualified people are capable of really understanding chemistry.	1 2 3 4 5
26.	To understand chemistry, I sometimes think about my personal experiences and relate them to the topic being analyzed.	1 2 3 4 5
27.	After I have watched a chemistry demonstration, I should be able to explain what I saw in terms of the reactions of atoms and molecules.	1 2 3 4 5
28.	The most crucial thing in solving a chemistry problem is finding the right equation to use.	1 2 3 4 5
29.	If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it.	1 2 3 4 5
30.	It is *unnecessary* for me to have to relate chemistry to the real world.	1 2 3 4 5
31.	Chemical demonstrations do not provide me with useful information although they can be fun and exciting.	1 2 3 4 5
32.	It is important that I finish a lab as quickly as possible – I'll figure out what the data mean later.	1 2 3 4 5
33.	Being able to visualize molecules in 3-D is an important skill for learning chemistry.	1 2 3 4 5

	1: Strongly Disagree 2: Disagree 3: Neutral 4: Agree 5: Strongly Agree	
34.	The results of an exam don't give me any useful guidance to improve my understanding of the course material. All the learning associated with an exam is in the studying that I do before it takes place.	1 2 3 4 5
35.	Learning chemistry helps me understand situations in my everyday life.	1 2 3 4 5
36.	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.	1 2 3 4 5
37.	Understanding chemistry means being able to recall something you've read or been shown.	1 2 3 4 5
38.	Spending a lot of time (half hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.	1 2 3 4 5
39.	When doing lab calculations, I attempt to work through them myself before looking for help from the lab manual or instructor.	1 2 3 4 5
40.	The main skill I get out of this course is to learn how to reason logically about the physical world.	1 2 3 4 5
41.	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.	1 2 3 4 5
42.	The chemical behavior of atoms and molecules has implications in my life.	1 2 3 4 5
43.	To able to use an equation in a problem (particularly in a problem I haven't seen before), I need to know more than what each term in the equation represents.	1 2 3 4 5
44.	When I do an experiment in the laboratory, it is not important that I understand what is happening. I should just follow the directions carefully.	1 2 3 4 5
45.	It is possible to pass this course (get a "C" or better) without understanding chemistry very well.	1 2 3 4 5
46.	I don't expect to use what I learn during one lab experiment in another experiment.	1 2 3 4 5
47.	Learning chemistry requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or read in the text.	1 2 3 4 5

Appendix C. Interview Guides and Consent Form

CHEMX: Assessing Cognitive Expectations for Learning Chemistry
Interview Consent Form

I understand that I am being asked to participate in an interview that will last approximately one half hour. The information gathered from this interview, will be used as part of a larger project looking at how students learn chemistry. I understand that this interview will be recorded and later transcribed to ensure the accuracy of the information collected. I do not have to answer any questions I do not want to and can stop the interview at any time and withdraw from the study. I understand that all personally identifiable information will be kept strictly confidential and will not appear in any reports generated using the information gathered from this interview. I understand that participation in the study is completely voluntary.

I've had the opportunity to ask any questions that I might have and they have been answered to my satisfaction. By signing below, I agree to participate in the interview.

______________________________ ______________

Research Participant Date

______________________________ ______________

Researcher Date

______________________________ ______________

Researcher Date

CHEMX Instructor Interview Guide

Introduction

- Restate purpose, context, and intended use of interview
- Assure confidentiality
- Ask for permission to tape
    - Turn on recorder
- Ask for questions

Background/General Information

- What is your educational background?
- What made you want to become a chemist?
- Pick one of the classes you are teaching this semester. During a typical class, what are your students doing?
    - What are you doing?
- What role do you think students play in learning chemistry?
- What role do you as the instructor play in the learning process?

[Member Check]

CHEMX Survey Items

I would now like to talk to you a bit about a few of the items on the CHEMX Survey. Give interviewee a copy of the survey and allow them to look it over for a few moments.

- Have interviewee read aloud and answer each pair of statements below (43 and 4, 6 and 41, 9 and 11, 24 and 18, 25 and 15, 35 and 30, and 44 and 39) explaining why they answered the way they did as they do so. If the interviewee realizes that he/she misread the statement, cross their answer out with a single line and circle the new answer. If interviewee changes their mind as they explain their answers, completely darken out the old answer and circle the new.

Cluster	Statements
Outcome	Only a very few specially qualified people are capable of really understanding chemistry.
	A good understanding of chemistry is necessary for me to achieve my career goals. A good grade is this course is not enough.

Reality-Link	Learning chemistry helps me understand situations in my everyday life.
	It is *unnecessary* for me to have to relate chemistry to the real world.
Laboratory	When I do an experiment in the laboratory, it is not important that I understand what is happening. I should just follow the directions carefully.
	When doing lab calculations, I attempt to work through them myself before looking for help from the lab manual or instructor.
Visualization	Solving a chemistry problem may require me to be able to draw molecules in more than one way.
	I don't spend much time constructing 3-D models of the 2-D structures I draw in my class notes or read in my textbook.
Math-Link	In this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens.
	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.
Concepts	To be able to use an equation in a problem (particularly in a problem I haven't seen before), I need to know more than what each term in the equation represents.
	Problem solving in chemistry means matching problems with facts or equations and then substituting values to get a number.
Effort	There is very little that I can do to test whether an answer I calculate is right (besides looking the answer up in the back of the book).
	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.

- ❖ Are there any other CHEMX items that stand out that you would like to share with me?

[Member Check]

Conclusion

- ❖ Summary
- ❖ Thank you
- ❖ Recontact with further questions?

CHEMX Student Interview Guide

Introduction

- Restate purpose, context, and intended use of interview
- Assure confidentiality
- Ask for permission to tape
    - Turn on recorder
- Ask for questions

Background/General Information

- Why did you decide to come to YSU?
- Currently, what is your major?
    - Why did you decide upon that particular major?
- Pick one of the chemistry classes you are taking this semester or have taken in the past. During a typical class, what is your instructor doing?
    - What are you doing?
- What do you think you need to do to be successful in learning chemistry?
- What role should the instructor play in your success?

[Member Check]

CHEMX Survey Items

If you remember, several months ago, you took the CHEMX Survey (give interviewee copy of survey) and I would now like to talk with you a bit about a few of the items on it.

- Have interviewee read aloud and answer each pair of statements below (43 and 4, 6 and 41, 9 and 11, 24 and 18, 25 and 15, 35 and 30, and 44 and 39) explaining why they answered the way they did as they do so. If the interviewee realizes that he/she misread the statement, cross their answer out with a single line and circle the new answer. If interviewee changes their mind as they explain their answers, completely darken out the old answer and circle the new.

Cluster	Statements
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	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.

- Are there any other CHEMX items that stand out that you would like to share with me?

[Member Check]

Conclusion

- Summary
- Thank you
- Recontact with further questions?