ABSTRACT

CHRISTIAN, CAROLINE MARIA. The Development and Validation of a Visual-Spatial Chemistry Specific (VSCS) Assessment Tool. (Under the direction of Maria T. Oliver-Hoyo).

Visual-perceptual skills are often overlooked in chemistry classrooms despite research showing a positive correlation between college students’ visual-perceptual abilities and problem-solving skills and negative correlations between visual-perceptual aptitudes and failure rates. Chemistry instructors are rarely formally trained in the nature of visual-spatial fields and may not be aware of its importance and relevance. Extensive research has been performed on general assessments intended to analyze students’ visual-perceptual abilities, yet these tests have not been combined into one easily administered and valid predictor of visual-perceptual ability for chemistry student. There has also been postulated a connection between success in chemistry and students’ ability to perceive molecules in different representations. The Visual-Spatial Chemistry Specific Assessment tool has been developed to address these concerns based on a theoretical framework. Its validity has been examined with regards to content, concurrent, and construct validity. The VSCS has been administrated to 816 students enrolled in general, organic, inorganic, and physical chemistry courses.
The Development and Validation of a Visual-Spatial Chemistry Specific (VSCS) Assessment Tool

by
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DEDICATION

I dedicate this work to the greatest teacher, mentor, and friend a person could ever hope and ask for, my mother, Alicemae Christian. She was the person who taught me to love education and reading by taking me to the library every weekend when I was a child, and it was there that I first learned that it was possible for me to reach for the stars. She also taught me how to think like a scientist, analytical and pragmatic, and taught me that if it isn’t your best it’s not worth doing. As a mentor, my mother helped shaped me into the woman, scientist, and educator I have become. When my mom was growing up, woman and scientist were rarely ever heard in the same sentence together, but in spite of these barriers my mother became a scientist. She was the person who taught me to go after my goals, no matter what they may be. My mother has been supportive of all my dreams and she has also been supportive in my failures. As a friend, my mother, has guided me, given me practical advice (even when I didn’t want to hear it), and helped me on my own pathway to success. Although my own path is not yet clear, I know that my mother will assist me in whatever way she can. The most amazing thing about my mother is that she did all this for me as a single parent, and she did it not once, but twice as she also raised my brother. She is also helping in the growth and development of my niece and nephew as well. So this work is dedicated to you, my momma, my teacher, my mentor, and my friend.
BIOGRAPHY

Caroline Christian is an educator because she likes to make a positive difference in students’ lives. She is a scientist because she is intrigued by the natural and physical world and hopes to find truth in the world by studying chemistry. She loves chemistry because it is in everything around us: everything we make has been influenced by a chemist, everything we do is controlled by our bodies’ biochemical processes, and everything that is living or nonliving has chemical properties.

She was born in Illinois on November 30, 1977, the second child to Bill and Alice Christian. When she was seven years old, her parents divorced and she moved to a small cottage next to a park. During these early years of her life she attended St. Andrews Lutheran School in Park Ridge, Illinois. It was at this small, private school that she got her early love of learning, teaching, and her good study habits. These habits have followed Caroline her whole life, turning her into a lifelong student, always thirsty for new knowledge. Peter, Caroline’s brother, got accepted to the University of South Florida when Caroline was eleven, so this prompted the whole family to move to Florida. While in Florida, Caroline developed her love for singing, singing in two duet and four solo competitions, five musicals, countless ensemble and choir competitions, and even made it to three all-state invitationals. She also found a new love in tenth grade, chemistry.

She attended Concordia University in River Forest, IL with a dream of becoming a high school chemistry teacher, but she quickly changed her career focus and decided instead to pursue college teaching. Caroline next went to the University of Illinois in Urbana-Champaign for Ph.D. studies, where she got her first true taste of teaching. She was
responsible for a twice weekly discussion section, and then a 4-day a week lecture section where the students only saw her to teach them chemistry. Needless to say, Caroline loved this interaction, and unfortunately her Ph.D. studies suffered for it. She decided to get a Masters’ Degree in Chemical Biology after four years of doing biophysical chemical research on a pathogenic bacterium – *Vibrio Cholera*. Then another teaching opportunity opened up for Caroline – a Masters’ degree in Education, where Caroline would be certified to teach middle and high school science. Caroline’s love for teaching lead her to complete this program in May of 2005, and graduate with two Masters’ degrees from the number six school in the country for chemistry programs.

Then another schooling opportunity opened up for Caroline, to pursue her dream of becoming a college chemistry instructor somewhere warmer, at North Carolina State University in Raleigh, NC. When she arrived, she came just as she had done three previous times in her life, with a chance to reinvent herself with no one who knew her, and unfortunately, no plans for any chemical education research. After about a year and a half of searching, she finally found a project that suited her – development of a Visual-Spatial Chemistry Specific assessment tool. Here she has found her place, where she wakes up every morning enthusiastic for the day to begin, yearning to go to work, and willing to learn new things. Caroline will be receiving her third Masters’ degree with the completion of this thesis and its defense, and she is excited to start on the next phase of her life where she hopes to get a job with a school board developing assessments.

“Why am I still a student? Because I love to learn new things everyday” - Caroline Christian
ACKNOWLEDGMENTS

I would like to acknowledge the help of my mentor, Maria T. Oliver-Hoyo, for helping me understand this topic, decide upon an assessment framework, listening to me at numerous group meetings, and helping me to revise pages and pages of text. She has been a generous and wonderful mentor, advisor, and friend. I would also like to acknowledge the help of the professors that have implemented the assessment in their classrooms, and the members of my committee, Dr. Jones, Dr. Ghiladi, and Dr. Whitten.

I would also like to thank the present and past members of my research group for listening to my group meetings, and giving me advice on how to make my research stronger.

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I would also like to thank the people in my life that made these last three and a half years the best years of my life. All my “school” friends: Laura, Deborah, Rich, Rachel, Steven, and others, all my “old” friends: Aimee, and Diana, all of my church, movie, and choir friends, but especially all of the students with whom I have interacted.

I would also like to acknowledge the help of my soul mate and one true best friend, Patrick Sloan, who helped me with the visualization and editing process of this thesis.

Finally, where would I be without the one constant force in my life, pushing me to do right, to be a better person, and to find my hour of peace a week, Dear Lord, thank you for bringing me on this fantastic journey that I call life.
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Chapter 1. Introduction:

Chemistry is a subject that requires its practitioners to think in the macroscopic, microscopic, and symbolic realms. Macroscopic includes what can be seen with the naked eye, while microscopic encompasses the particulate nature of matter. The symbolic realm entails the equations and mathematics used in chemistry. Embedded in all three realms are visual-perceptual skills, which are defined as the skills being involved in forming mental images of visual objects. However, visual-perceptual skills are often overlooked in chemistry classrooms and chemistry instructors are rarely trained or aware of the relevance of visual-perceptual skills in chemistry. It should be noted that there is a pedagogical difference in this thesis’ two main terms: visual-spatial and visual perceptual skills. Visual-spatial skills refer to the ability to observe relations of objects in space. Chemistry students need visual perceptual skills because before they can see the relation of an object in space (visual-spatial skills), they first need to cognitively form a mental image of that object (visual-perceptual skills). Only after students grasp what the object looks like in three-dimensions are they able to compare other objects to it. Visual-spatial is only referred from now on by its connection with the tests and assessments used to measure these types of skills. Visual-perceptual skills dictate the necessity of visual-spatial assessments in order to test them.

Visual-perceptual skills are important to scientists, especially chemists, because of the spatial nature of representations of molecules. Molecules, atoms, and the ways they interact are at the heart of chemistry and chemists model them three-dimensionally based on
experimental research and data. The three most common ways to represent molecules are space-filling, ball and stick, and line drawings. Space filling models show more accurately what the atoms look like in the molecule by representing their electron clouds according to modern quantum theory. Ball and stick models show how the atoms are connected together with balls representing the atoms, and sticks representing the bonds between atoms. Line drawings are the most simplified way to represent molecules, and often the most confusing to chemistry students. In line drawings, lines represent carbon to carbon bonds, and students must interpret what the molecule looks like in three-dimensions from a two-dimensional stick drawing in order to understand the structure-function relationship of the molecule. Visual-perceptual skills make understanding the different representations of chemistry molecules an achievable goal.

Eight theoretical visual-perceptual skills have been proposed as important for chemistry students to have. They are: visual association, visual constancy, visual discrimination, visual figure-ground, visual form perception, visual memory, visual orientation, and visual sequencing. Their definitions are listed in Table 1.1. Published visual-spatial tests generally test only one type of visual-perceptual skill, visual orientation, which is basically the ability to rotate three-dimensional objects that are represented in two-dimensions. The eight visual-perceptual skills have only been theorized about, and have never been tested before. The main goal of this research is to develop and validate a visual-spatial assessment that includes these eight visual-perceptual skills for its use in college chemistry classrooms. Ultimately this assessment may be used to screen students’ visual-perceptual skills, monitor their skill development, or evaluate the effects of an intervention.
Table 1.1: Definitions of theoretical visual-perceptual skills proposed for chemistry

<table>
<thead>
<tr>
<th>Visual-perceptual skill</th>
<th>Definition (Ability to)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual association</td>
<td>relate concepts written as text to their representation in pictures</td>
</tr>
<tr>
<td>Visual constancy</td>
<td>see diagrams of objects that are the same size, shape, or color from others that are not</td>
</tr>
<tr>
<td>Visual discrimination</td>
<td>perceive dominant features in objects and to discriminate one object from another</td>
</tr>
<tr>
<td>Visual figure ground</td>
<td>distinguish objects from their background</td>
</tr>
<tr>
<td>Visual form perception</td>
<td>represent in two- or three-dimensions objects that are three-dimensional</td>
</tr>
<tr>
<td>Visual memory</td>
<td>recollect the dominant features of a diagram</td>
</tr>
<tr>
<td>Visual orientation</td>
<td>rotate the positions of objects in space in relation to other objects and the observer</td>
</tr>
<tr>
<td>Visual sequencing</td>
<td>see objects in a particular order</td>
</tr>
</tbody>
</table>

The foundation of this theory is a compilation of case studies of students assessed as having average intelligence and who exhibited one or more learning deficits. Examples of these deficits include: motor-memory dysfunction, reversals, insertions, deletions, errors in visual perception and interpretation. The visual-perceptual theoretical framework that this visual-spatial assessment is based on was first hypothesized as being important for engineering, astronomy, and anatomy students. The researchers hypothesized that students who lack specific cognitive or visual perceptual learning abilities may fail courses in their academic careers. The study concludes that students who have these difficulties overcome them by compensating with their strengths, such as a student who has a visual input disorder supplementing with an auditory input. They also advocated helping these students, “By clearly identifying the underlying componential perceptual and visual skills essential for mastery, the need to overcome the students’ deficiencies as quickly as possible may be ameliorated”.
The development of a chemistry specific assessment of these eight visual-perceptual skills started by identifying test questions from various sources,6, 7, 8, 9 evaluating those questions to ensure that they tested visual-perceptual skills, and aligning them to the theoretical framework of visual-perceptual skills. (See Chapter 4.) Only those questions with relevant chemistry content were used. Testing conditions considered included length of test, number and difficulty of questions, clear and understandable wording of questions, and ordering of questions from easiest to hardest within the specific categories. The Visual-Spatial Chemistry Specific (VSCS) assessment is intended to test all eight visual-perceptual skills by asking spatial ability questions to different levels of chemistry undergraduates.

An important goal of an assessment such as this is to verify its validity. According to Fink, there are four different types of validity for an assessment tool; content, construct, predictive, and concurrent validity.10 Content validity refers to how the VSCS assessment thoroughly and appropriately assesses the visual-perceptual skills it is intended to measure. Researchers often maximize the content validity by testing students using a specific theoretical framework. In this case the visual-perceptual framework from Rochford’s work was used to select items for the visual-spatial assessment.3 Construct validity is related to how correlated the assessment is to the visual-perceptual framework that is being tested. Predictive validity refers to the extent to which the assessment measures future performance. Concurrent validity may be demonstrated when two assessments agree, and the Purdue Rotation of Visualization Test was chosen since this assessment tool also measures visual orientation skills and has been validated in college chemistry classroom settings.4
The purpose of the VSCS tool is to test college students’ visual-perceptual skills by conveying visual-spatial questions in the context of chemistry molecules. The purpose of this research is to develop and validate this visual-spatial assessment tool that college chemistry students and instructors can use to evaluate visual-perceptual skills.

1.1 References:


Chapter 2. Literature Review:

Although there are a considerable number of research studies and papers that describe spatial ability, this review will concentrate on visual-spatial tests and visual-perceptual skills, which are skills required to produce a mental reproduction of an image. This literature review has three main sections:

- **Theoretical Frameworks** – discussing the frameworks that have shaped this and others’ work in the field.
- **Visual-Spatial Tests/Assessments** – discussing the past and present tools that have been developed to assess these skills.
- **Validation of the Tools** – discussing the procedures and means used to validate visual-spatial assessments.

All the research studies discussed in this review have been performed with college students, unless otherwise stated. The three sections in the literature review will follow a chronological order.

2.1 Theoretical frameworks:

Theories regarding the teaching of chemistry that tie into visual-perceptual skills began with Johnstone’s theory of the three realms of chemistry: macroscopic, microscopic, and symbolic.\(^1\) In this researcher’s view, to comprehend chemistry a student must first be able to recognize a molecule, combine it with other molecules to form chemicals, and break the molecules down to form atoms. All of these processes require that students form mental pictures of these concepts. Macroscopic chemistry processes utilize visual-perceptual skills to help the students form a mental picture of the chemical contents. Especially difficult to
grasp for most students, microscopic chemistry requires the student to form mental images of modeled structures prior to understanding the chemistry involved.\textsuperscript{1} Symbolic chemistry’s connection with visual-perceptual skills comes from the hypothesis that the initial step to solve a problem is to visualize the steps involved.\textsuperscript{2}

Dual Coding theory explains human behavior and performance by invoking educational theory and looking at three realms: education, affective skills, and perceptual-motor processes.\textsuperscript{3} Some researchers have used Dual Coding theory as a theoretical framework for their visual-spatial research.\textsuperscript{4,5} According to this theory, which was first published in 1986, there are two important systems required to teach: nonverbal imagery or imagens, and verbal linguistic or logogens.\textsuperscript{3} Both of these systems are separate yet interconnected because they are both used to explain the senses; however both of the systems are different in internal structure because they are describing two parts of one whole. One system can trigger activity in the other, but the pathways are usually incomplete which is why it is imperative to teach with both systems especially in chemistry classrooms. Chemistry is a particularly visual subject and, for example in organic chemistry, visual representations of hydrocarbons and other molecules are used interchangeably with verbal descriptions of them. If the pathways in human performance are incomplete in regards to their verbal and nonverbal systems, then teachers must make these connections explicit for students.

Wiley’s Hierarchy of Visual Learning, published in 1990, focused on college engineering graphics students.\textsuperscript{6} Based partly on the work of Piaget,\textsuperscript{7} Wiley theorized three primary stages of visual learning, which he identified as developmental states individuals
pass through while on their way to visual maturity. The three stages of primary visual learning are visual cognition or perceiving a visual image, visual production or creating a visual object and visual resolve or comprehending the purpose of a visual object. (See Figure 2.1)

![Diagram of primary stages of visual learning](image)

**Figure 2.1: Hierarchical stages of visual learning**

The first stage, visual cognition, is involved in forming mental images of visual objects; this is the definition of visual-perceptual skills. According to this theory, the other two stages of visual learning cannot be achieved by students until they attain adequate visual-perceptual skills. Piaget assigned children ages to specific cognitive stages, and although Wiley did not specify such age ranges, he talks about the engineering graphics community lack of focus on the visual skills of college students. The hierarchy of visual learning by college graphic engineering students concentrates on the difficulties that college students could have while developing their visual maturity and it also represents the kinds of problems that any college student may have with regards to visual-perceptual skills. This study
concluded that students who are not in the advanced levels of this hierarchy will not be successful in engineering graphics classes. This paper also points out that researchers have developed new and recycled old terms to describe visual-perceptual skills such as spatial cognition and spatial visualization, although in this thesis the terms visual-spatial and visual-perceptual will be defined consistently throughout.

Rochford theorized that there were eight important visual-perceptual skills needed to succeed in science and engineering classes. The visual-perceptual framework was proposed by Rochford after looking at case studies of above average intelligence students who were poor visualizers. These case studies showed that the students were having trouble with various aspects of visualization, such as discrimination or orientation skills. The researchers theorized that students may fail subjects such as engineering, astronomy, and anatomy if they lack these specific visual-perceptual abilities. It is argued in this thesis that these same skills are necessary for college chemistry students to succeed as well.

Visual-perceptual skills have two different components that are regularly tested, analytic versus holistic skills. Analytic skills are defined as those being utilized when solving visual-spatial questions via logical means. An analogy to the use of analytic skills is like looking at landmarks in order to arrive at a destination. The students are basically dividing the objects into pieces and then altering parts of the object to find the correct answer. Holistic skills on the other hand are used when an individual studies the entire figure, and transcribes it in their mind by looking at the whole object. An analogy for using holistic skills is looking at a map to understand where one is going, encompassing the entire figure. Bodner claims that holistic skills are the skills that are being truly tested by visual-
spatial assessments since they are represented by looking at the full object, forming a mental picture of it, and then comparing it to the other objects.\(^9\)

Another theory that emphasizes visual-perceptual skills when solving visual-spatial questions is the Schema Theory of Cognitive Structures.\(^{10}\) Schema may be defined as a personal scientific pattern imposed on an experience to assist in explaining it. Students can solve chemistry problems by activating an appropriate schema such as an equation that will help students find the correct answer. Although equations and algorithms may be the easiest way to solve problems in some cases, they usually do not lead to understanding what the question is asking.\(^2\) The Schema Theory encourages students to use different representations when solving chemistry problems, which in turn may help them answer the question. It has been found that performance on problem solving tasks increases when high school students use drawings or are shown drawings about chemistry questions.\(^{10}\) They also found that students’ ability to switch from one representation to another in an organic chemistry classroom is the main difference between students who are successful and students who are not.\(^{10}\) A representation can be a drawing of a molecule, a verbal description of a molecule, or the molecule’s formula. The results of this study led researchers to believe that the cause of these students’ ability comes from thinking of chemical systems in terms of the microscopic nature of matter.\(^{10}\)

Recent research in this field has mainly focused on the development of computer simulations and programs aimed at improving students’ visual-perceptual skills, while giving them some specific chemistry knowledge. Wu, et al.\(^4\) conducted a research study about the visual-perceptual skills of college chemistry students and found that students can not
interpret chemical representations, provide equivalent representations for a given representation, or make transformations from 2-D to 3-D representations. In their study they state that with improved visual-perceptual skills all these conceptual mistakes can be corrected. They used a computer visualizing tool, eChem, to help students develop their understanding of chemical representations. eChem provides three different ways a student can interact with the program: “construct” lets students build covalent compounds, “visualize” lets students see multiple representations of molecules from different angles, and “analyze” lets students experience the connections between the microscopic (molecular structures) and the macroscopic realms (collective physical behaviors). They found that, “Students who were highly engaged in discussions while using eChem made referential linkages between visual and conceptual aspects of representations. The findings also suggest that computerized models can serve as a vehicle for students to generate mental images…”.

Electrochemistry is a cognitively complex topic, and visual computer animations were employed by Greenbowe to help chemistry students understand electrochemistry. These animations not only show the math behind calculating electrochemical potentials, but also use animations to illustrate what is happening inside a flashlight and its battery. In this study, two groups of students were used: one was given computer graphics animations representing electron and ion movement in batteries, while the other group was shown static pictures of the same concepts. All the students were given a diagnostic test to assess the students’ chemistry knowledge before they started the class, a knowledge pretest and posttest, and a visual-spatial assessment - the Purdue Rotation of Visualization Test (ROT). In this test, respondents are asked to inspect one three-dimensional solid object in two
different rotations, surmise the rotation between them, and make the same rotation with another three-dimensional solid object to choose which object has the same rotational pattern from among five different choices.\textsuperscript{10, 12} This test assesses the visual orientation skill set, which is defined as rotating the positions of objects in space in relation to other objects and the observer. On a transfer post-test students who saw the animations did better on it, as well as the students with higher scores on the Purdue ROT. This research study strongly suggests a need for further research on the connections between spatial ability and computer animations.

Problem solving skills have been shown to be highly correlated with visual-perceptual skills.\textsuperscript{11} For example in 2003, Wu’s literature review\textsuperscript{12} comprised studies that correlated spatial abilities and chemistry problem solving,\textsuperscript{2, 5} literature that identified student’s conceptual mistakes and struggles understanding visual representations,\textsuperscript{13, 14} and research in how to design visualization tools to transfer knowledge into different visual representations.\textsuperscript{4, 15} (The visualization tools covered were only computer animation systems, not assessment tools.) The results of Wu’s literature review reflected that students’ conceptual errors in chemistry are due to difficulties in working in different visual-spatial representations, for example translating a chemical formula into its molecular structure. They suggested five principles for designing chemistry classroom visualization tools: “(1) providing multiple representations and descriptions, (2) making linked referential connections visible, (3) presenting the dynamic and interactive nature of chemistry, (4) promoting the transformation between 2D and 3D, and (5) reducing cognitive load, making the information explicit, and integrating the information for students.”\textsuperscript{12}. There has been
some argument whether or not the conceptual errors identified in Wu’s literature review arise from a lack of higher order formal thought or from a lack of visual-perceptual skills.\textsuperscript{16} Research is vital to determine whether achievement in chemistry is due to increased formal thought ability, increased visual-perceptual ability, or a combination of the two.

Most theories of visual versus verbal learners consider only one type of visual learner (such as the Dual Coding theory). This unitary theory of visual learning was rejected in 2006 by Blanjenkova et al\textsuperscript{17} when they developed a new self-reporting instrument, the Object-Spatial Imagery Questionnaire (OSIQ). This group supports a dual theory of visual learners: object imagers or individuals who prefer processing colorful and pictorial images and spatial imagers or people who prefer processing schematic and spatial relationships. Object imagers utilize primarily holistic skills as they prefer viewing high-resolution objects while spatial imagers utilize primarily analytic skills as they prefer to encode objects part by part. Visual artists would most likely be object imagers, while scientists would most likely be spatial imagers. The researchers found that the OSIQ discriminates between object and spatial imagers.

2.2 Visual-Spatial Assessments/tests:

Different theoretical frameworks have spawned different types of assessments to test chemistry students’ visual-perceptual skills,\textsuperscript{18, 19, 20, 21} including those that use general diagrams and are therefore not related to science fields, but have been used in chemistry classrooms.\textsuperscript{9} Visual-perceptual skills were first tested and studied by Thurstone in the 1930’s.\textsuperscript{22} As a pioneer in the field, his book contained a variety of tests for visual-perceptual skills. He considered these skills to be a part of an individual’s primary mental abilities, and
coined the term factor analysis to determine the primary factors involved in the different mental capabilities. He also ran the first factor analysis to determine what the essential skills were, by giving 240 volunteers 56 different general visual-spatial assessments. Factor analysis is a data reduction technique used when a large number of variables are observed and the goal is to reduce these variables to a smaller number of latent (unobserved) factors. Thurstone hypothesized two such factors; the first was the skill to see in 2-dimensions, and the second the skill to see in the 3-dimensions. He tested both of these skills with a number of visual-spatial assessments and concluded that although they were considered separate categories tentatively for visualizing in flat and solid space, the analysis did not show a division. Since then, others have published general tests and guidelines for assessing these types of skills, and others have used factor analysis to find various important features about the visual-perceptual skills they are testing.

2.2.1 General visual-spatial assessments:

A general visual-spatial test based on assessment questions developed by Shepard and Metzler was created by Vandenberg and Kuse. The Shepard and Metzler test asked people to just look at two different rotations of block figures (two dimensional drawing of a three dimensional figure) to find out if the blocks were the same or different. This study tested if the response time would increase when increasing the angle of rotation between the two figures. (See Figure 2.2) The results showed an increased response time, in fact a linear increase. Vandenberg and Kuse made a paper-and-pencil type test using the same type of figures. Their rotation test is related to the visual memory skills that are important in
Rochford's framework, which are defined as recollecting the dominant features of a diagram. The test presents one reference figure with four others rotated in different directions, and the goal is to find the two that are the same as the reference figure. Most of the incorrect answers are mirror images of the reference figure. They gave the test to elementary school children, and they claim that it may be useful in studies of spatial ability development.

Figure 2.2: Example question from the Shepard and Metzler test

Psychologists studied another set of achievement tests using factor analysis and showed that there are at least ten different achievement factors for students to master before they leave school. Two of the achievement factors have counterparts in the eight visual-perceptual skills highlighted in this thesis. The first achievement factor is spatial orientation which is related to visual orientation skills, or the ability to rotate positions of objects in space in relation to other objects and the observer. Spatial orientation is defined as “perception of position and configuration of objects in space, perhaps best thought of as space with the observer himself as a reference point.” An example of a spatial orientation question from the Cube Comparison test shows a picture of two six-sided cubes, with only three sides visible to decide if the cubes are the same or different (See Figure 2.3). The challenging aspect is that the cubes are rotated in different directions so one must try to rotate
the cube and form a mental picture of it, to see if it matches with the other cube in a set amount of time.

![Figure 2.3: Example question from the Cube Comparison test](image)

The second factor identified is the visualization factor, which corresponds to the discrimination skill, or the ability to perceive dominant features in objects and to discriminate one object from another. Visualization factor is described as “the ability to manipulate or transform the image of spatial patterns into other visual arrangements”. An example of a test of this sort is the Surface Development test. An example question in this test is a picture of a two-dimensional piece of paper cut so that it can be folded into the three-dimensional object given. One is required to match the folds on the piece of paper with the edges on the three-dimensional object (See Figure 2.4). This test has been used in intelligence and career assessments.

![Figure 2.4: Example question from the Surface Development test](image)
The Embedded Figures test was first developed for military purposes, and it differentiates between field independence and dependence, or analytic versus holistic thinkers. A holistic thinker likes to look at the whole picture first, while an analytic thinker likes to break things up into parts. Students who have a field independence cognitive learning ability (analytic thinkers) tend to perform better on this test. An example test question is featured in Figure 2.5 where the students are given a simple shape and asked to identify the shape in different patterns. A form of the Embedded Figures test was developed by Witkin in 1977, and it has also been used in science classrooms to test the embedding ability of field dependence/independence.

Figure 2.5: Example question from the Embedded Figures test

Children observed to have difficulties with the visual-spatial realm of learning were denoted as having nonverbal learning disabilities. These nonverbal learning disabilities were first noted and reported by Rourke in 1989. There have been visual-spatial assessments
developed and published for children with these types of disorders as well. A nonverbal learning disability is more severe than not being able to solve visual-spatial questions. Children who have these disorders have motor and social problems along with visual-spatial problems but they have very strong verbal skills and usually memorize well. The assessments rely on the strengths of the students, by asking them to remember the position of objects in a grid, giving a blank grid, and asking the students to recall the location of the objects. These assessments used to test children are simpler than the questions described in this thesis, although they can be made more challenging by adding more spaces on the grid and more objects to the assessment.

2.2.2 Chemistry assessments:

Organic chemistry is a strongly visual-spatial dependent field because of its inherent nature to draw molecules as simplified representations of their true form. Therefore, students with visual-spatial handicaps tend to find organic chemistry very challenging. One research study used specific training sessions employing three-dimensional molecular models. This research found that the students who received this specialized training improved their performance in a college-level general chemistry course. Another research study published ten years later, used specific training conditions for their experimental group that emphasized the development of visual-spatial skills by giving students workbooks that demonstrated visualization skills. This study showed that students who received this special training scored significantly higher on exams that included questions using three-dimensional models than the control group who received the same amount of training on nomenclature of chemical compounds.
There have been a number of visual-spatial assessments developed especially for chemistry students. One of these tests is the Depth Cues assessment by Seddon et al.\textsuperscript{36, 37, 24} There are four different depth cues as illustrated in Figure 2.6: relative size cue, or the size of the atoms with respect to one another; overlap cue, or the amount of overlap that happens between the ball (atom) and stick (bond); foreshortened line cue, or the lengths of the bonds; and distortion of angles cue, or the angle variation that happens in the molecular structure.

Figure 2.6: A diagram of the four depth cues in an octahedral molecule

The Depth Cues assessment has ten questions for each of the four depth cues, and it tests students’ ability to look at the model from the correct viewpoint, and choose which one of the diagrams is the best representation.\textsuperscript{38, 39} They used both photographs and drawings of the molecules and found that the students performed about the same with either representation.\textsuperscript{38} Additionally, these studies showed that high school and college aged students regularly missed questions concerning the relative size of objects and the foreshortening of straight lines.\textsuperscript{39}
Seddon also developed the Molecular Rotation, Reflection and Inversion tests that assess visual orientation skills. These tests are intended to identify high school students from different cultures who were spatially prepared. The Molecular Rotation test had thirty different questions, with ten different molecules around three different axes of rotation, and Molecular Reflection test had twenty-six reflection questions. In one study Seddon showed molecules rotating in successive steps using an overhead projector and found that with this type of visual aid students understood better if the diagrams were in color. Interestingly enough the results also illustrated that there was a limit to the amount of colors that should be shown. Additionally, results pointed to the fact that to rotate correctly in the X- and Y- axes depth cues are needed, but in the Z-axis no depth cues are needed to solve the problem.

Although all the previous chemistry assessments mentioned up to this point have only tested visual orientation skills, there have been others who published test questions that this researcher believes test the additional visual-perceptual skill categories. Rochford et al. wrote the Visualization of Molecular Pictorial Structures assessment tool with questions that were not associated to any of the visual-perceptual skills, but could be used to test these skills. Rochford correlated students’ scores on this visual-spatial assessment with achievement rates of chemistry students. He found that there was a positive correlation, meaning that students who did not do well on this assessment would underachieve significantly in college chemistry courses. Rochford, however, never related the Visualization of Molecular Pictorial Structures test questions to his theoretical framework of
eight visual-perceptual skills. This critique of their research methodology is a weakness that this research aims to address.

Tuckey’s research study looked at the steps involved in solving a rotation type problem and found that at the university level, students still have problems with rotating a molecule around an axis. The study broke down the skills necessary to solve a visual orientation problem into six elementary steps which include: 1) visualizing the molecule on the paper, 2) recognizing the axis, 3) recognizing the molecule in reference to the axis, 4) visualizing three dimensions, 5) drawing the structure, and 6) picking the correct answer by comparing the possible choices. They developed an assessment that tested the six elementary steps and a short two hour intervention program where they basically went over the steps necessary to solve this type of problem. The experimental group did statistically better on the posttest than the control group did. The study concludes that the university students had troubles with their visual-perceptual skills, and that these problems were corrected with a short intervention that covered these simple steps. “It is therefore recommended that student competence in the basic concepts and skills required for three-dimensional thinking be tested and any shortcomings rectified”.

The Space Test provides test questions that fit with the visual association skill set, which are relating concepts that are in words and pictures. These test questions utilized pictures of unit cells and asked students to count, infer, and deduce how many different elementary pieces were in each picture. Barke found that males have superior visual-perceptual skills to females before intervention, although in other studies there was no significant correlation. They researched differences in genders of students by providing
training to both genders using molecular models. Their results showed that when girls were given molecular models they scored as well as the boys on their spatial ability test.\textsuperscript{42}

General visual-spatial tests have also been employed in more recent research studies looking at chemistry students’ visual-perceptual skills.\textsuperscript{9} One such test is the Purdue Rotation of Visualization Test, and although this test has been reported before it was described most clearly in 1997.\textsuperscript{9} The Purdue ROT has been used in chemistry classrooms, but it was not designed specifically for chemistry students. With this test visual-perceptual skills have been shown to be positively correlated to chemistry students’ problem solving skills.\textsuperscript{2} They postulate this is because one of the first steps in solving a chemistry problem is visualizing the chemical compounds, goals, steps, and mathematical process. They determined this by giving students the Purdue Rotation of Visualization Test at the beginning of the semester, and then statistically correlating various grades received on various assignments, tests, and final exams to this visual-spatial test score. Results showed that the grades received on problem solving activities were positively correlated with the visual-spatial test score. This implies that visual-perceptual skills are important for students to use when solving chemistry problems.

Savec et al. updated Seddon’s Molecular Rotation and Reflection test questions, and used computer technology to let high school and college students manipulate the molecules before making their selections.\textsuperscript{44, 20} The study looked at which of six molecular representations students used to solve increasingly complex problems: 3-dimensional model in box, photo of the 3-dimensional model, computer generated model, colored schematic representation of the model, black and white schematic representation of the model, and
stereochemical formula. Results of their research indicate that the correct perception of the 3D molecular structure is crucial for all further intellectual operations. Students’ scores on this assessment tool decreased significantly when the task became more complex even though the students used the same representation of the molecules. When the task used several mental processes, the score was even lower. They concluded that in chemistry education close attention must be paid to how complex the task of rotation is, the students’ age and mental ability, and the type of representation given for the molecule. The second study by the same researchers tested how different molecular representations, either a computer representation or a physical model, would help chemistry students. They found that the computer representations are a bridge between 3-D molecular representations and 2-D representations, and that the physical models, virtual representations, and a combination of both types, are equally useful to students in supporting perception of the molecular structure.

2.2.3 Assessments for other science disciplines:

Blade and Watson showed that students in the engineering field developed their visual-spatial abilities even during their first year of studies. In another study by Rochford first year engineering students were given a series of tests such as the Geometric Battery Test, which included several different assessments such as the Surface Development test described above, and Engineering Drawing tests. They found that offering remedial attention to the students who fail the visual-spatial exams increased their retention in the program. It was recommended that a visual-spatial exam be the key in identifying students who would pursue either a 4-year or 5-year program.
Rochford’s anatomy test included pictures of an organ drawn incompletely where medical students had to analyze the drawing to identify the organ. In this research study the scores received on this specialized anatomy visual-spatial test were highly correlated with scores on other classroom assessments, such as the Geometric Battery Test. Students who did not do well on this specialized anatomy visual-spatial assessment were more likely to drop out of medical school. The researchers postulate this is because anatomy and other science subjects are highly visual subjects. Students were given this specialized visual spatial test at various times throughout their college and medical school careers. They found that visual-spatial scores were negatively correlated with the failure rates of the students. This means that students who did poorly on the visual-spatial assessments were more likely to fail these science classes, and ultimately drop out of medical school.

In 1998 Rochford conducted a study to assess astronomy students’ visual-perceptual skills as well, by correlating scores on regular astronomy exams to a specific astronomy visual-spatial assessment. The astronomy visual-spatial assessment scores were used to divide the students into visually able and visually deficient groups. The visually able group of students were more likely to pass the astronomy exams and hence the class.

A content based geospatial examination was developed and tested on geology students to see whether their skills would increase after training using QuickTime virtual reality instructional modules. Skills did increase on this uniquely designed geology visual-spatial examination with interesting differences in the genders. Although the females performed poorer than the males did in pretesting the students, at the post-test females had
improved to have equal scores with the males. The experimental group demonstrated increased spatial ability as compared to the control group at the end of the experiment.

2.3 Validation of published tools:

A variety of visual-spatial assessments have been developed, tested and validated for different areas of education. The four main sources that were used to develop the Visual-Spatial Chemistry Specific tool were Seddon’s Molecular Reflection and Rotation assessment, \(^{36,40,24}\) Savec’s reworking of these questions, \(^{44,20}\) the Space Test, \(^{42,43}\) and Rochford’s Visualization of Pictorial Molecular Structures test. \(^{41}\)

Validation is defined as the degree to which an assessment measures what it is intended to measure. Researchers have recognized the importance of visual-perceptual skills and visual-spatial assessments and have validated tests of this domain of educational study. Seddon et al. have tested different groups of students from different countries that included Nigeria, Portugal, England, Pakistan, and Cape Verde. The Molecular Rotation and Reflection assessments that test visual orientation skills had the construct validity verified with high school and college students in Pakistan and Cape Verde. The questions asked students to rotate molecules around a specific axis of rotation, to find which of the axes were psychologically distinct in the student’s minds. \(^{37}\) They found that this task was not successful in transference of the learning to any of the different axes or planes. These studies strongly suggest that the X, Y, and Z axis are factorially and psychologically distinct concepts in students’ minds. \(^{23,24}\)

Rochford validated the Visualization of Pictorial Molecular Structures assessment and found that “from 1986-1988, significant relationships have been found between 1) the
spatial visualization abilities of chemistry students at the University of Cape Town and 2) their academic achievements in class tests and examinations in chemistry”. Students who failed this assessment underachieved significantly after a semester of general chemistry and those who did better on the assessment did better in chemistry classes. Language was ruled out as an issue since on an English proficiency test the students who underachieved did as well as their spatially prepared peers.

The Space Test, a German test, tried to identify the age that students first cultivate spatial ability. This spatial ability was related to concrete formal thinking processes as formulated by Piaget. The Space Test was given along with a general intelligence test to seventh, eighth, and ninth grade students. A correlation between the two scores indicated that the spatial ability of the students developed as strongly as general intelligence. The results found that in seventh grade the two scores were not correlated, but became correlated in the eighth and ninth grade. The authors suggest that teachers should avoid problems that require the use of spatial ability to students in seventh grade. In eight and ninth grade, however, teachers should begin to use problems that use concrete structures because at this age, most students are in Piaget’s “concrete operations of thinking” stage.

Kovac tested the construct validity of selected spatial ability tests by correlating the students’ class grades with the scores of three commercially available visual-spatial tests. They were trying to determine if the tests were only measuring holistic ability, or if they were measuring analytic trial and error ability for eight graders. Their results showed that none of the tests truly measured holistic ability. However; there have been other research
reports that claim visual-spatial tests do measure holistic ability, more specifically the Purdue Rotation of Visualization Test\textsuperscript{9}.

Ferk, et al\textsuperscript{44} did a face validity study on a rotation and reflection assessment in 2003 by testing students using computer animations of the molecular representations, where the students could manipulate the figures with the mouse. Students were interviewed and asked whether they would prefer the computer models or physical models to solve the questions. Students expressed preference for either the computer models or the physical models but when given both, the students scored lower because their attention was divided.

Johnson and Bouchard tested which of three educational models of intelligence fits a study of assessments by using principal factor analysis\textsuperscript{53}. They gave 436 people 42 different mental ability tests, and published the results in 2005. Prior to this study others had categorized students’ test scores and then developed a theory from the results. In this paper three theories were considered and individuals were tested using known psychological mental ability tests to see which theories fit better. A statistical Principal Components Analysis (also called factor analysis) indicated that a verbal-perceptual model of viewing intellectual thought was the best fit. This model had three different factors: a general intelligence factor, a verbal and educational factor, and a spatial, practical and mechanical abilities factor. This third factor is the one that is being tested with the VSCS assessment tool.

This literature review strongly suggests that visual-perceptual skills are crucial when switching from one chemistry representation to another because of the need to visualize in all three realms of chemistry: macroscopic, microscopic, and symbolic. Improvement on skills
involved in mental representation of objects could be attained by interventions such as explicitly showing students different visual-spatial representations. The need for high quality visual-spatial assessments still exists as well.  

2.4 References:


Chapter 3. Methodology

3.1 Research Design:

This thesis reports on a comprehensive tool for assessing visual-perceptual skills structured around the theoretical framework of Rochford and Archer.\(^1\) This theoretical framework of eight visual-perceptual skills was chosen because each of the identified skills were clearly described, it was suitable to test with the Visual-Spatial Chemistry-Specific (VSCS) assessment tool and had never been used before in the chemistry visual-spatial assessment field. Questions included on the VSCS assessment were located in a variety of sources,\(^2,3,4,5\) and only questions taken from assessment tools that had been validated with science students were included.

The VSCS assessment was coded into an electronic homework program, Webassign (http://webassign.ncsu.edu). This program delivers the assignment to the students, collects homework at a specified time, and grades homework while giving immediate feedback to the students. The Visual-Spatial Chemistry Specific assessment was not designed to be a timed test, so students were given a week to work on the VSCS “homework” assessment. The program allows students to log in, work on the assignment, and save their work before submitting the assignment. Although giving the students only one submission was pondered in order to align the test with a traditional paper and pencil test, two submissions were granted due to the complexity of some of the test questions. The VSCS assessment tool was not meant to frustrate any student but to generate answers that truly reflected their abilities.
The VSCS assessment participants were categorized by the chemistry class in which they were enrolled. The chemistry classes were solicited by asking professors of each major undergraduate chemistry course to participate. The courses involved in this study included:

Table 3.1: Courses and number of students involved in Visual-Spatial Chemistry Specific assessment implementation during the 2007/2008 school year

<table>
<thead>
<tr>
<th>Class</th>
<th>Fall 2007</th>
<th>N</th>
<th>Spring 2008</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Chemistry</td>
<td>101 for majors (1 section)</td>
<td>44</td>
<td>101 (1 section)</td>
<td>228</td>
</tr>
<tr>
<td>Organic Chemistry (I = 221 and II = 223)</td>
<td>221 (2 sections)</td>
<td>157</td>
<td>221 (3 sections)</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td>223 (1 section)</td>
<td>38</td>
<td>223 (1 section)</td>
<td>175</td>
</tr>
<tr>
<td>Inorganic Chemistry</td>
<td>401 (1 section)</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Chemistry (majors = 431/433, nonmajors = 331)</td>
<td>431</td>
<td>27</td>
<td>331</td>
<td>60</td>
</tr>
</tbody>
</table>

3.2 Research questions:

The Visual-Spatial Chemistry Specific or VSCS assessment is unique in that it is based entirely on a visual-perceptual framework. This research aims to assess eight visual-perceptual skills which are being proposed chemists need.

1. Is it possible to develop a valid visual-spatial assessment that would discriminate between eight theoretical visual-perceptual skills?

It was hypothesized that a valid assessment could be developed by selecting questions from other published visual-spatial assessments to test the eight theoretical visual-perceptual skills. The Purdue Rotation of Visualization test was chosen to determine the concurrent validity of the VSCS due to the fact it had already been validated in chemistry classrooms, and could directly be related to one of the eight visual-perceptual skills, the visual orientation skills.
2. How many factors will come out when a Principal Component Analysis statistical technique is used to analyze the VSCS assessment?

This question was asked because of the theoretical framework of visual-perceptual skills that the assessment was based on. The principal component analysis was hypothesized to show eight factors, one for each of the eight visual-perceptual skills identified by Rochford and Archer.¹

3. Will the VSCS assessment tool show any differences in scores of students who are in a beginning general chemistry class versus students who are in more advanced chemistry classes?

It is hypothesized that if students are taking more advanced chemistry classes that require a more sophisticated visualization skill set, then the students’ visual-perceptual skills should be more advanced and this should show on an assessment designed specifically for testing visual-perceptual skills.

3.3 Implementation:

The Visual-Spatial Chemistry Specific assessment tool was first implemented in the Fall of 2007 in four different chemistry courses: General chemistry for majors (n=44), Organic chemistry I (n=157), Organic chemistry II (n=38), and Physical chemistry (n=27). A total of 266 students took the VSCS assessment at its pilot stage. Student feedback showed the need to make questions more understandable to students. For instance, the reflection questions appeared to be the most challenging, so an example was added to illustrate the specifics of such a problem. Questions were further revised to improve conveying their meaning. In addition, various categorical and opinion questions were added,
including a question regarding the students’ permission for their test scores to be used anonymously and for research purposes only.

The revised VSCS assessment was implemented in the Spring of 2008 in five different chemistry courses: General chemistry (n=228), Organic chemistry I (n=317), Organic chemistry II (n=175), Physical chemistry (n=60), and Inorganic chemistry (n=36). A total of 816 students took the revised VSCS assessment, and their first submission data was statistically analyzed. Using only first submission data is better aligned to evaluate and compare our results to other research reports that used paper and pencil visual-spatial assessments.

3.4 Data analyses:

3.4.1 Construct validity: Factor analysis

An accepted statistical approach in educational testing situations such as this is Principal Component Analysis (PCA). Principal component analysis is useful when there is redundancy in the variables, which means “that some of the variables are correlated with one another, possibly because they are measuring the same construct” or factor.\(^7\) For example, Seddon had used PCA with his data on the visual-orientation skills of different groups of students from different countries, and he found that the different cultures made a difference in how many factors were involved.\(^8\) For this study PCA was chosen to reduce the data to the principal factors since it was hypothesized that the data would clearly differentiate into eight different factors corresponding to the eight visual-perceptual skills of Rochford and Archer’s theoretical framework.\(^9\) The VSCS assessment includes 47 visual-spatial questions with at least four questions addressing each visual-perceptual skill.
The statistical analysis was run using SAS software. Usually PCA is performed on continuous data, but the VSCS assessment’s data is binary. A series of 0’s and 1’s indicated whether the student got the question incorrect (0), or correct (1). The binary data needs to be interpreted as continuous data in order to use PCA. The technique of Latent Trait Analysis helped to correct for this by modeling an association between an individual’s response to a question (0 or 1) and the latent or unobserved continuous variables which are derived from the raw binary data. Latent Trait Analysis assumes that the binary data is continuous data by calculating a threshold score based on the students’ answer to the question. The threshold score is the measure that decides if the student answered the question correctly (above the threshold score) or incorrectly (below the threshold score). This threshold score is the key to finding the continuous scores or latent variables.

The latent variables calculated were used to set up a tetrachoric correlation matrix. The tetrachoric correlation matrix estimates the correlation matrix of the unobserved continuous data. The goal is to perform a PCA on the tetrachoric correlation matrix of the unobserved (latent) variables to find how many latent factors there are and to determine the relationships between the latent variables and the latent factors, which are assumed to be the real factors that describe the binary data. A summary of the statistical methods used is shown in Figure 3.1.
3.4.2 Extracting number of principal components:

With no restrictions on the numbers of factors the initial PCA determined eigenvalues which represent the amount of variance in the data that can be attributed to a specific factor. Higher eigenvalues indicate factors of greater importance as they are a measure of explained variance or variance that can be described. A plot of eigenvalues versus factor number is called a scree plot. When the magnitude of the eigenvalues drop drastically in the scree plot, then the remaining factors should not be included in the analysis because they account for very little of the observed variance. The name scree plot comes from the fact that these plots look like sides of mountains, and the need is to distinguish between the side of the mountain and the “scree” at the bottom. Another way to extract the principal components (primary factors) is to use the Kaiser Criterion, which includes keeping all the eigenvalues that are above one as significant components or factors. Figure 3.2 is an

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**Figure 3.1:** Statistics flowchart of Principal Components Analysis done on the Visual-Spatial Chemistry Specific assessment.

**Figure 3.2**

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**Tetrachoric Matrix Example**

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>-</td>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>Q2</td>
<td>a</td>
<td>-</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>Q3</td>
<td>b</td>
<td>c</td>
<td>-</td>
<td>e</td>
</tr>
<tr>
<td>Q4</td>
<td>c</td>
<td>d</td>
<td>e</td>
<td>-</td>
</tr>
</tbody>
</table>

**Raw Binary Data Example:**

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student 1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**Latent trait analysis** assumes data comes from latent continuous variables by modeling an association between the binary data and the latent variables.

**PCA on Matrix** – find number of latent factors = Actual factors

(Scree plot versus Kaiser Criterion to determine number of factors)
example scree plot which shows two important factors, however using the Kaiser Criterion on the same example data yields four factors with eigenvalues above one.

![Scree Plot](image)

**Figure 3.2: An example of a scree plot**

### 3.4.3 Reliability test:

Cronbach’s $\alpha$ measures internal consistency or reliability and it is the average of the correlations for all the different questions in an assessment tool. The equation for Cronbach’s $\alpha$ is

$$\alpha = \frac{Nc}{\nu + (N - 1)c},$$

where $N$ is the number of observed variables (number of questions), $c$ is the average covariance between variables, and $\nu$ is the average variance of observed variables. A Cronbach’s $\alpha$ that is close to unity indicates that the assessment has high internal consistency among all items. A value that is close to unity may also indicate that only one factor is present, because the assessment measures the same skill and one factor is all that is needed to explain the data. The Cronbach’s $\alpha$ was also calculated to compare it to the number of factors determined by Principal Components Analysis.
3.4.4 Differences among different classes:

A variance analysis was run to see if there were significant differences between the different classes. The research hypothesis was that there would be differences in mean student scores corresponding to the level of the chemistry course involved. ANOVA (analysis of variance) is a standard statistical technique commonly used to compare two or more different sets of data. However, if the assumptions of normality and equal variance for each class’ data were violated, then the non-parametric technique of Kruskal-Wallis should be used. The Kruskal-Wallis technique uses the rank of the values, rather than the numbers themselves, and allows the researcher to ignore the restraints of normal data and equal variance. The Kruskal-Wallis technique also produces a p-value, and if that p-value is greater than the desired error rate $\alpha$ value then the null hypothesis can not be rejected and the differences between the two classes is non significant.

In the Kruskal-Wallis analysis the comparisons were made between the seven different classes of chemistry students who took the Visual-Spatial Chemistry Specific assessment, therefore the desired error rate alpha value needs to be corrected because there were multiple hypothesis tests run on the same set of data. The Bonferroni correction on the desired error rate is utilized by dividing the alpha value by the number of comparisons. In this case with 7 different classes compared against all others, there are 21 possible comparisons, therefore $\alpha$ will now equal $0.05/21 = .00238$ to give a 95% error rate. The Bonferroni correction is a safeguard against multiple tests of statistical significance on the same data which could give the appearance of false significance, as 1 out of every 20 hypothesis tests will appear to be significant at the $\alpha = 0.05$ level by accident.
Interaction studies were conducted to see if the students’ responses to categorical and opinion questions were reflected in the scores. The categorical question was, “How many semesters of organic chemistry have you completed?” The opinion questions were “How much effort did you put into this assignment?” and “How much time did you put into this assignment?” The parametric statistical method ANOVA was used to determine an interaction between the students’ scores and their answers to these three questions. ANOVA was used here because the assumptions of normality were met, which means that all 816 students scores fall into a bell shaped curve. If the ANOVA p-value is greater than the desired error rate alpha value (95%, $\alpha = .05$), then the students’ answers to the categorical and opinion questions will not significantly influence their scores.

3.4.5 Concurrent Validity test:

A random sample of 26 students was taken from the 816 students who took the Visual-Spatial Chemistry Specific assessment, and were given the Purdue Rotation of Visualization test. This test was chosen to validate the VSCS tool since it has been shown to be a valid measure of the cognitive ability of visual-perceptual skills, although it tests only visual orientation skills. The students’ percentages on the VSCS assessment and the Purdue Rotation of Visualization test were computed, and the differences in the individual students’ percentages determined. In addition, the students’ percentages on the ten VSCS assessment questions that tested visual orientation skills and their score on the Purdue Rotation of Visualization test were compared as well. A paired t-test, which means that the two percentages compared come from the same individual, was performed to determine if the mean differences were significant.
3.4.6 Sources of variation:

There are three sources of variation or statistical dispersion which could explain the response variable (in this case test score); (a) the observational component (variation measured), (b) the confounding component (variables whose effects can not be separated), and (c) variation due to unidentified sources (the error variation). Previous visual-perceptual knowledge would be a confounding component as it can not be separated from any of the variables measured, such as the students’ estimation of time and effort put into the assignment, or level of chemistry class. The variation due to unidentified sources is an error that can not be explained therefore can never really be corrected. The experimental components, response variables, and potential confounding components are listed in Table 3.2.

Table 3.2: Variation components and variables for the Visual-Spatial Chemistry Specific assessment

<table>
<thead>
<tr>
<th>Name</th>
<th>Alternate name(s)</th>
<th>Section in VSCS assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response variable</td>
<td>Dependent variable</td>
<td>Test scores</td>
</tr>
<tr>
<td>Explanatory variable</td>
<td>Independent variable or Observational component</td>
<td>-Chemistry class</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Major</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Number of semesters - organic chemistry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Estimation of time and effort put into the VSCS assessment</td>
</tr>
<tr>
<td>Confounding component</td>
<td></td>
<td>Previously acquired visual-perceptual skills</td>
</tr>
</tbody>
</table>

The need to develop a new benchmark in testing students’ visual-perceptual skills prompted the development of the VSCS assessment tool. Correlations have been shown between visual-perceptual skills and skills that chemistry students need to succeed. Studies have looked at failure rates in medical school and showed them to be negatively correlated with visual-perceptual skills. Researchers have also looked at the correlation
between problem solving skills and visual-perceptual skills, and have found them to have a positive correlation. This is theorized to be important because of the obvious implications it carries for students who are enrolled in chemistry departments.

3.5 References:


Chapter 4. The Instrument: Visual-Spatial Chemistry Specific (VSCS) Assessment Tool:

It is postulated that students need eight specific visual-perceptual skills to understand the microscopic realm of chemistry. The VSCS assessment provides a compilation of questions chosen specifically to assess these types of skills in a multiple choice and fill in the blank format. There are 47 questions on the VSCS tool, but only ten are highlighted here to show how these represent the different types of skills. The following example questions are introduced with a definition of the primary skill being tested, the test question with its figure, and an explanation on how the set of questions assess the specific types of skills. Table 4.1 summarizes the number of the questions on the VSCS assessment that test the specific skill, the questions that will be discussed in this section, and what the students are asked to do in the specific questions.

Table 4.1: Summary of questions, skills assessed, and what the students are asked to do

<table>
<thead>
<tr>
<th>Question #s on VSCS tool</th>
<th>Question(s) discussed</th>
<th>Skills assessed</th>
<th>Students are asked to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>4</td>
<td>Visual discrimination</td>
<td>discriminate between different hollow wire frameworks</td>
</tr>
<tr>
<td>6-10</td>
<td>10</td>
<td>Visual figure ground</td>
<td>recognize a figure and its background</td>
</tr>
<tr>
<td>11-20</td>
<td>11,17</td>
<td>Visual orientation</td>
<td>rotate and reflect diagrams of molecules in terms of the observer</td>
</tr>
<tr>
<td>21-25</td>
<td>25</td>
<td>Visual form perception</td>
<td>interpret 3-D representations of molecules in a 2-D manner</td>
</tr>
<tr>
<td>26-30</td>
<td>27</td>
<td>Visual sequencing</td>
<td>see images in a certain order or sequence</td>
</tr>
<tr>
<td>31-34</td>
<td>31</td>
<td>Visual memory</td>
<td>remember what a figure looks like</td>
</tr>
<tr>
<td>35-39</td>
<td>35</td>
<td>Visual constancy</td>
<td>recognize if figures of molecules are the same size, shape or color</td>
</tr>
<tr>
<td>40-47</td>
<td>40, 41</td>
<td>Visual association</td>
<td>relate concepts in diagrams and words</td>
</tr>
</tbody>
</table>
1. **Visual discrimination skills** involve an ability to perceive dominant features in diagrams, and to discriminate one image from another. “Students with a problem in this area could experience difficulties with inversions, transformations, equivalences, congruencies, and reversals with subsequent confusion of symbols or diagrams”.¹

**VSCS Example Question #4:**

In this question, the framework of a wire figure reference image is drawn on the left. On the right are three diagrams suggesting how this hollow wire model might appear when viewed from different angles. In each case either all three diagrams are possible views or only two of the diagrams are possible and one drawing could never be observed no matter what your angle of view.

Pick either the number of the diagram which could **never** be observed, or if all of them could be observed, pick number **"4"**.²

---

![Reference image.

<table>
<thead>
<tr>
<th><img src="image1.png" alt="Diagram 1" /></th>
<th><img src="image2.png" alt="Diagram 2" /></th>
<th><img src="image3.png" alt="Diagram 3" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2.</td>
<td>3.</td>
</tr>
<tr>
<td>All of these could be observed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.1: Example question from the visual discrimination skill set
**Explanation:** This question’s correct answer is 4 since all the diagrams are comparable to the reference image, just viewed from different angles (response 1), different sides (response 2), and different corners (response 3). This question was picked to differentiate between inversions, transformations, equivalences, congruencies, and reversals by having all three possible diagrams analogous to the reference. In this question, students need to perceive dominant features, such as angles, triangular faces and rectangular faces, in order to discriminate one image from another. Response 1 necessitates viewing the reference diagram from a slightly different angle and recognizing that the triangular faces are actually equilateral triangles. This illustrates the concept of equivalences or images that are equivalent and congruencies or images that are consistent. Response 2 requires viewing the reference diagram by reversing or looking at the diagram in an opposite position or direction, since one needs to turn the image around and view it from one of the rectangular faces. Response 3 entails inverting the reference diagram and looking at it from the top rectangular corner; inversions involve turning upside down or setting an object on end. Transformations which are defined as a change in form or appearance are observable in all the options, since all the diagrams are different in appearance from the reference image.
2. **Visual figure-ground skills** involve objects being distinguished from their background. “Students with difficulties in this area may experience problems identifying patterns”.

**VSCS Example Question #10:**

The diagram below is an illustration of the structure of diamond. Each lettered black dot represents an atom of carbon and all are in the cube. For each question choose the one best response.

Look at atom letter U; it is attached to 4 other atoms H, J, L, R. Look at atom letter H; it is only attached to 2 other atoms U and T. It should be attached to 4 atoms. Should atom H’s other two atoms it is attached to be outside the cube or inside the cube?

![Figure 4.2: Example question from the visual figure ground skill set](image-url)
**Explanation:** The answer is outside the cube due to the pattern of points drawn on the diagram. The positions of the carbon atoms are represented by the black points in the diamond structure. “U” has its four atoms, two down (L and R) and two up (H and J), therefore “H” should have the same pattern, two down (U and T), and two up (outside the cube). Looking at this structure one can view many different lines and points which make up the pattern, or the consistent form, or style of the diagram. The most important patterns to note are the solid lines which denote the outside edge of the box. The other important lines are the dotted lines which make up the inside of the box; there are two vertical planes at right angles to each other, and two horizontal planes, in the middle and the bottom of the box. Identifying patterns is distinctive in this test question since all the lines provide the background reference that students need to distinguish the position of the carbon atoms that make the diamond structure.
3. **Visual orientation skills** involve being able to perceive the positions of objects in space in relation to other objects and the observer. Students with problems in this area have troubles with spatial relations.$^{1}$

a. **Spatial orientation skills** involve what three-dimensional representations will look like from a different perspective (rotation skills).

**VSCS Example Question #11:**

If the structure in diagram A were rotated about the **Y-axis** in the direction that the axes show, which diagram below would represent the structure as seen after a rotation of 180 degrees?$^{3,4}$

![Diagram A and rotation axes](image_url)

**Figure 4.3: Example question from the visual orientation (rotation) skill set**
Explanation: In order to come up with the correct answer, one must compare the molecule in diagram A to the set of axis (the observer) and then compare this molecule to the four responses (other objects). This type of question tests visual orientation skills, as students must be able to perceive three-dimensional molecular representations and rotate or turn them around a central axis to a different perspective, or mentally move them according to an anchor which in this case is understood to be the central atom.

Students need spatial relations, which are defined as how an object is located in space in relation to some reference image, to solve this visual orientation question. These types of questions are the first listed in the VSCS assessment tool that utilize depth cues; depth cues are used to give the appearance of depth in a 2-dimensional drawing of a molecule (See Figure 2.6). These molecular representations are set on a black background and there is nothing in the individual representations to relate them to each other, so they are considered as being in space.
b. **Spatial relation skills** involve reflection and inversion.

**VSCS Example Question #17:** Among the molecular representations 1-4 choose the one which you would get after reflecting molecule A in the mirror.³, ⁴

![Molecule A and Mirror](image)

![Figure 4.4: Example question from the visual orientation (reflection) skill set](image)

**Explanation:** Reflection is reversing the right and left of the image according to a fixed plane; the only option that does this with the red atom at the bottom of the molecule is 3. These molecular representations are on a white background with nothing to relate them to any of the other images. Spatial orientation skills and spatial relation skills are related but distinct terms. They both use the depth cues, and they both involve perceiving the positions of images in space in relation to other objects and the observer. They are distinct because the spatial orientation skills involve rotation of the molecular representations around a fixed point, in this case the central atom, while spatial relation skills reflect the molecular representation through a fixed plane, in this case the mirror.
4. **Visual form perception skills** involve three-dimensional objects being represented by two- or three-dimensional diagrams. Students with problems in this area will distort, deform and create disproportional representations.¹

**VSCS Example Question # 25:**

The diagram below is a ball and stick representation of a molecule of isobutane

![Diagram of isobutane molecule](image)

The hydrogen atom which is farthest from the hydrogen atom labeled “H” is hydrogen atom number ______.², ⁴

Figure 4.5: Example question from the visual form perception skill set

**Explanation:** The solution to this question is 1, and this test question utilizes depth cues to have students visualize the 3-dimensional nature of the object. When students distort or twist the picture out of its original form the location of the objects is misrepresented. When students deform or misshape the structure they will perceive the atoms to be larger or smaller than they are, and this will lead to disproportionate representations.
5. **Visual sequencing skills** involve the ability to see images in a particular order. Students could have problems with omissions, insertions, or substitutions of symbols with deficiencies of this type of skill.¹

**VSCS Example Question #27:**

The diagram below illustrates the regular crystal lattice structure of zinc sulfide. The positioned black dots represent ions of zinc and numbered white circles represent sulfide ions. There are 18 ions represented in this unit cell.

View the ion labeled 8. Is ion number two above or below ion eight?²

![Diagram](image-url)

Figure 4.6: Example question from the visual sequencing skill set
**Explanation:** The solution to this question is that ion number 2 is above ion number 8 due to the specific order in which the ions are arranged. The zinc ions (black 1-4) are in the center of the box, one in four of the eight quadrants of the box, while the sulfur ions (white 5-18) are on the corners and sides of the box (at midpoints). Table 4.2 describes the order of the sulfur ions.

Table 4.2: Sulfur (white) ions in visual sequencing figure and their order

<table>
<thead>
<tr>
<th>Ions</th>
<th>Location</th>
<th>Ions</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-7</td>
<td>Across top of box in diagonal</td>
<td>12-14</td>
<td>Across bottom of box in diagonal</td>
</tr>
<tr>
<td>8, 9</td>
<td>On the back and right midpoints of the box</td>
<td>15, 16</td>
<td>On the front and left midpoints of the box</td>
</tr>
<tr>
<td>10</td>
<td>On the top right hand corner</td>
<td>17</td>
<td>On the top left hand corner</td>
</tr>
<tr>
<td>11</td>
<td>Directly below 10</td>
<td>18</td>
<td>Directly below 17</td>
</tr>
</tbody>
</table>

Ion 8 is on the back of the box on the middle horizontal line. Students can see this because there are five sulfur ions at the top of the box, five at the bottom, and four on the faces of the box in the middle; 8 is one of these. Ion 2 is in the front right hand corner of the box above the mid dotted line of the box where ion 8 is located. Students visualize this because ion 2 is attached to the four closest white ions to it, just like the rest of the zinc ions. The lines are important in this figure as well since solid lines represent the outside of the box that the viewer sees, and the dotted lines make up the inside of the box. Omissions or insertions (leaving out or adding something to the diagram) could be viewed by omitting the dotted line or by inserting an extra line around ion 8. Substitutions or other symbols taking the place of each other may occur by placing a line (the horizontal line ion 8 rests on) or an ion (7) between 8 and 2.
6. “Visual memory is the ability to recollect the dominant features of a stimulus item or to recall the order of a number of items presented visually. Students with problems in this area may have difficulty recognizing geometric objects and symbols accurately”.

VSCS Example Question #31:

In the next question four different diagrams of the given molecule are presented, suggesting how the molecule would appear when viewed from different angles. In each case, three of the four diagrams are of the same molecule, whereas one of the four diagrams is incorrect because it shows a mirror image of the molecule.

For example and are mirror images

Pick the one molecule out of the four that is a mirror image to the others.

Figure 4.7: Example question from the visual memory skill set
**Explanation:** The correct answer to this question is number 4 since it is the only one that is a mirror image of the other molecules (1-3). Diagrams 3 and 4 are obvious mirror images of each other because they have the same orientation (green atom up) but the yellow and red atoms are reversed. When rotating both diagrams 1 and 2 so that they have the green atom up and the white atom to the side, they match diagram 3. The perfect way to test visual memory skills would be to show students a diagram of a molecule, then have it disappear and ask them questions about it, but unfortunately the computer program does not have this function. A way to simulate this type of skill is to give students representations of molecules that they need to commit to short term memory in order to answer the question. This occurs when students recognize one main point, the central atom, in all of the structures at one time and determine mirror images around the central atom. Geometric objects, such as the tetrahedral molecule shown in this example question, could be difficult to recognize if a student does not have an understanding of depth cues. For instance, looking at response 1 it is a hard to tell that the two side atoms are sticking out at the viewer if one did not have a grasp of the overlap depth cue. The symbols shown in this question are the atoms, the lines (bonds), the molecules and the depth cues. Both geometric objects and symbols are important in understanding a question of this type and answering it correctly.
7. **Visual constancy skills** involve the ability to see diagrams of objects that are the same size, shape, or color from others that are not. Students with problems in this area misinterpret changes in size, shape, or color of objects.¹

**VSCS Example Question #35:**

Two different types of models of organic molecules are illustrated below: SPACE FILLING models and BALL-AND-STICK models. Space filling models more closely resemble the actual shape of the molecule as the electron clouds are represented. Ball-and-stick representations with elongated bond lengths show more clearly how one atom is connected to the next. In the next question, you are provided with a ball-and-stick model of an organic molecule. Set out below it are four diagrams of space-filling models of organic molecules. The models may be rotated in any direction.

Pick the space-filling model that matches the ball-and-stick model.²

Figure 4.8: Example question from the visual constancy skill set
**Explanation:** The correct answer to this question is 1, since it is the only one that has all four white atoms in the correct orientation around the central gray atom. These questions test visual constancy skills since they require to observe different representations of molecules using depth cues and to determine if they differ in size (there are different constituents on each possible molecule), they differ in shape (different orientations of the same and different molecules), and they differ in color (different identities of the atoms in the molecules). The reason that 2 is not the correct answer is because although there are the correct numbers of white atoms shown on the gray central atom, they are not in the correct shape. Both 3 and 4 differ in size from the example with the incorrect number of white and gray atoms. All incorrect answers differ in shape from the tetrahedral ball and stick reference structure.
8. **Visual association skills** involve the ability to relate concepts which are represented in pictures and written words. Students’ problems include being “unable to identify figures that are presented in fragments or unable to visualize the missing portion of a partially incomplete object or diagram”.

**VSCS Example Question #40-43**

For questions 40-47 refer to the diagrams that are associated with each question.

These diagrams are pictures of three-dimensional unit cells that are represented by cubes or spheres that have been stacked on one another.

How many cubes are needed to fill the hollow part (in the middle) of the structure? (Q40). Treating the hollow portion as one cube, how many cubes make up this structure? (Q41).  

![Diagram](image.png)

Figure 4.9: Example question from the visual association skill set
**Explanation:** To identify correctly that there are four missing cubes in question 40 students need to visualize the missing portion of the incomplete diagram and relate it to fragments or to the small detached portion of the lines that connect the other blocks. The association between the written text and the figure is necessary to correctly answer question 41 as 21. This question is asking to include the middle unit as one “cube” in the counting process and then there are 6 cubes on each side, 4 on the top and bottom of the middle unit, and 1 as the middle unit itself.

4.1 References:


Chapter 5. Results:

The Visual-Spatial Chemistry Specific assessment was developed to test a theoretical framework of eight visual-perceptual skills proposed by Rochford and Archer. After the VSCS tool was developed and coded into an electronic homework system, it was given to 816 college undergraduates taking chemistry at North Carolina State University in a variety of courses. Four types of validity were considered for this assessment: content, predictive, concurrent, and construct validity. The validity inferred from the assessments is essential since it is the commonly accepted way to determine if the assessment tests what it is intended to measure; a way to reduce bias and distortion. Content validity was maximized by developing the assessment around the eight visual-perceptual skills theoretical framework. Predictive validity would best be measured by giving the assessment to the same students at different stages in their academic career and correlating their scores to academic success. The timeframe for this work was restricted within a semester course and the VSCS assessment was only given at the end of the semester. Therefore, predictive validity was not measured. Concurrent validity entails establishing two assessments statistically concur. Construct validity involves correlating the assessment with the theoretical framework that was used to develop it. Concurrent and construct validity are discussed below.

5.1 Concurrent validity:

To test concurrent validity 26 students chosen at random were given the Purdue Rotation of Visualization test (ROT) since this test has been validated as a predictor of visual-perceptual skills, specifically visual orientation skills. Both the whole Visual-Spatial Chemistry Specific test and the ten questions in the VSCS assessment identified to test visual
orientation skills were compared by paired t-tests to the scores on the Purdue ROT. The result of comparing the whole VSCS assessment to the scores on the Purdue ROT was a p-value of 0.070, and comparing the ten orientation questions to the Purdue ROT gave a p-value of 0.352. Choosing a predetermined α-value of 0.05 for a 95% acceptance level, these results indicate no significant differences between the VSCS test scores and the Purdue ROT test scores for a random sample of 26 students. A 95% acceptance level was chosen since this is the value used most often for statistical purposes in the literature regarding visual-spatial assessments.

5.2 Construct validity:

Construct validity (how accurately the theoretical framework is correlated with the assessment) was determined by Principal Components Analysis (PCA) which calculates correlations between the different questions on the assessment. If the correlation between any two questions is high, then the two questions could have a common factor, or a common visual-perceptual skill that influences both of them. Variance in the data arises from differences in the correlations of the factors. A factor is important in Principal Components Analysis when it describes a large proportion of the variance in the data. The initial PCA will give eigenvalues for 47 different factors corresponding to the 47 different questions on the tool. An eigenvalue measures how much variance there is in the data, so the higher the eigenvalue, the higher the variance in the data that is described by those factors. In other words, a higher eigenvalue means more variance was extracted from that particular factor. Table 5.1 includes a list of selected eigenvalues from the tetrachoric correlation matrix, the proportion of variance the factor describes, and the cumulative variance. The proportion of
the variance is the percentage of the variance that is described by the factor. The cumulative variance combines the variance from the factors up to and including the factor in question. The first factor listed is the one with the highest eigenvalue (or variance) and the rest are the factors that account for lesser variance.

Table 5.1: Selected factor numbers and associated eigenvalue, the proportion of variance described, and the cumulative variance

<table>
<thead>
<tr>
<th>Factor Number</th>
<th>Eigenvalue</th>
<th>Proportion of variance</th>
<th>Cumulative variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20.3140067</td>
<td>43.22</td>
<td>43.22</td>
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<tr>
<td>2</td>
<td>2.2970239</td>
<td>4.89</td>
<td>48.11</td>
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<td>3</td>
<td>1.8085690</td>
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<td>4</td>
<td>1.5398187</td>
<td>3.28</td>
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<td>47</td>
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<td>-0.46</td>
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</tr>
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</table>

In determining the number of important factors from a PCA there are two common methods one could use, the Kaiser Criterion and the scree plot. The Kaiser Criterion
considers important factors that have eigenvalues above one because to keep a factor that factor must extract the equivalent of one original variable. The data in Table 5.1 shows there are nine factors with eigenvalues above one.

The second method used is a plot of eigenvalues versus factor number, or a scree plot. The key in determining the number of factors from this plot is to view where the graph has a sudden downward turn. The upper factors are important in the graph, and the rest of the factors are just “scree” at the bottom. In the scree plot pictured in Figure 5.1 it can be seen that after the first factor there is a large drop off, meaning that one factor predominates the data analysis.

![Scree plot for Spring 2008](image)

Figure 5.1: Scree plot from Spring 2008 data
The first method (Kaiser Criterion) commonly retains too many factors, while the second technique (scree plot) may retain too few, and both of these methods are subjective tests of how many factors to retain. The case for one factor versus nine factors is further complicated by the fact that factor 1 accounts for 43% of the explained variance, and factors 2-9 account for 25% of the explained variance. The next step in determining how many factors to keep is to examine the factor loadings, which are numbers that describe the correlation of the factor to the question.

After the number of factors are found, the latent variables (question scores) must be fit to a linear equation due to the fact that PCA is based on a generalized linear model. For example, if two factors are found then the equation

\[ x = \lambda_1 \cdot f_1 + \lambda_2 \cdot f_2 + e \]

describes the factor results for each of the questions, where \( x \) = student’s true score, \( \lambda \) = factor loadings, \( f \) = factors, and \( e \) = an error term. The true score equals an additive combination of the factor loadings multiplied by the factors themselves plus an error term. Factor loadings may determine which questions have higher correlations to the factors identified. A high factor loading for an observed variable (test question) on a particular factor indicates that this individual factor is greatly influencing the score of the test question. Factor loadings above a 0.3 are considered significant using PCA in the SAS program. In Table 5.2 the factor loadings from the first factor only (which accounts for 43% of the variance and is identified in the scree plot) are listed. In the first factor all the questions in the VSCS (except questions one and two) have factor loadings above 0.3. In Table 5.3 all the factors with factor loadings above 0.3 are listed.
Table 5.2: Factor loading correlations of the one factor from the Principal Component Analysis on the 47 questions of the VSCS assessment (* = significant factor loading)

<table>
<thead>
<tr>
<th>Question #</th>
<th>Skill tested</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Factor loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Discrimination</td>
<td>0.13622</td>
</tr>
<tr>
<td>2</td>
<td>Discrimination</td>
<td>0.27099</td>
</tr>
<tr>
<td>3</td>
<td>Discrimination</td>
<td>0.33712*</td>
</tr>
<tr>
<td>4</td>
<td>Discrimination</td>
<td>0.34841*</td>
</tr>
<tr>
<td>5</td>
<td>Discrimination</td>
<td>0.35645*</td>
</tr>
<tr>
<td>6</td>
<td>Figure ground</td>
<td>0.60366*</td>
</tr>
<tr>
<td>7</td>
<td>Figure ground</td>
<td>0.55689*</td>
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<td>8</td>
<td>Figure ground</td>
<td>0.57282*</td>
</tr>
<tr>
<td>9</td>
<td>Figure ground</td>
<td>0.52362*</td>
</tr>
<tr>
<td>10</td>
<td>Figure ground</td>
<td>0.52221*</td>
</tr>
<tr>
<td>11</td>
<td>Orientation</td>
<td>0.40192*</td>
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<td>Orientation</td>
<td>0.61321*</td>
</tr>
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<td>Orientation</td>
<td>0.52159*</td>
</tr>
<tr>
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<td>Orientation</td>
<td>0.70375*</td>
</tr>
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<td>Orientation</td>
<td>0.58002*</td>
</tr>
<tr>
<td>16</td>
<td>Orientation</td>
<td>0.61121*</td>
</tr>
<tr>
<td>17</td>
<td>Orientation</td>
<td>0.76724*</td>
</tr>
<tr>
<td>18</td>
<td>Orientation</td>
<td>0.52434*</td>
</tr>
<tr>
<td>19</td>
<td>Orientation</td>
<td>0.53702*</td>
</tr>
<tr>
<td>20</td>
<td>Orientation</td>
<td>0.52247*</td>
</tr>
<tr>
<td>21</td>
<td>Form perception</td>
<td>0.78709*</td>
</tr>
<tr>
<td>22</td>
<td>Form perception</td>
<td>0.84296*</td>
</tr>
<tr>
<td>23</td>
<td>Form perception</td>
<td>0.58234*</td>
</tr>
<tr>
<td>24</td>
<td>Form perception</td>
<td>0.63651*</td>
</tr>
<tr>
<td>25</td>
<td>Form perception</td>
<td>0.67615*</td>
</tr>
<tr>
<td>26</td>
<td>Sequencing</td>
<td>0.80052*</td>
</tr>
<tr>
<td>27</td>
<td>Sequencing</td>
<td>0.68053*</td>
</tr>
<tr>
<td>28</td>
<td>Sequencing</td>
<td>0.73996*</td>
</tr>
<tr>
<td>29</td>
<td>Sequencing</td>
<td>0.83507*</td>
</tr>
<tr>
<td>30</td>
<td>Sequencing</td>
<td>0.87603*</td>
</tr>
<tr>
<td>31</td>
<td>Memory</td>
<td>0.62408*</td>
</tr>
<tr>
<td>32</td>
<td>Memory</td>
<td>0.62717*</td>
</tr>
<tr>
<td>33</td>
<td>Memory</td>
<td>0.47312*</td>
</tr>
<tr>
<td>34</td>
<td>Memory</td>
<td>0.60244*</td>
</tr>
<tr>
<td>35</td>
<td>Constancy</td>
<td>0.90326*</td>
</tr>
<tr>
<td>36</td>
<td>Constancy</td>
<td>0.84511*</td>
</tr>
<tr>
<td>37</td>
<td>Constancy</td>
<td>0.64808*</td>
</tr>
<tr>
<td>38</td>
<td>Constancy</td>
<td>0.65575*</td>
</tr>
<tr>
<td>39</td>
<td>Constancy</td>
<td>0.76345*</td>
</tr>
<tr>
<td>40</td>
<td>Association</td>
<td>0.93133*</td>
</tr>
<tr>
<td>41</td>
<td>Association</td>
<td>0.70236*</td>
</tr>
<tr>
<td>42</td>
<td>Association</td>
<td>0.82917*</td>
</tr>
<tr>
<td>43</td>
<td>Association</td>
<td>0.81007*</td>
</tr>
<tr>
<td>44</td>
<td>Association</td>
<td>0.75735*</td>
</tr>
<tr>
<td>45</td>
<td>Association</td>
<td>0.59563*</td>
</tr>
<tr>
<td>46</td>
<td>Association</td>
<td>0.77415*</td>
</tr>
<tr>
<td>47</td>
<td>Association</td>
<td>0.76824*</td>
</tr>
</tbody>
</table>
Table 5.3: Factor numbers and their factor loadings that are above the cutoff value of 0.3 for the 47 questions on the VSCS assessment tool

<table>
<thead>
<tr>
<th>Q #</th>
<th>Skill tested</th>
<th>Factor 1 (factor loading)</th>
<th>Factor 2-5 (factor loading)</th>
<th>Factor 7-9 (factor loading)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Discrimination</td>
<td>5 (0.487)</td>
<td>7 (0.312)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Discrimination</td>
<td>4 (0.556)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Discrimination</td>
<td>1 (0.334)</td>
<td>4 (0.374)</td>
<td>8 (0.339)</td>
</tr>
<tr>
<td>4</td>
<td>Discrimination</td>
<td>1 (0.346)</td>
<td>4 (0.545)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Discrimination</td>
<td>1 (0.358)</td>
<td>4 (0.440)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Figure ground</td>
<td>1 (0.602)</td>
<td>2 (0.369)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Figure ground</td>
<td>1 (0.585)</td>
<td>2 (0.412)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Figure ground</td>
<td>1 (0.570)</td>
<td>2 (0.503)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Figure ground</td>
<td>1 (0.523)</td>
<td>2 (0.614)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Figure ground</td>
<td>1 (0.520)</td>
<td>2 (0.354)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Orientation</td>
<td>1 (0.411)</td>
<td>3 (0.395)</td>
<td>9 (0.327)</td>
</tr>
<tr>
<td>12</td>
<td>Orientation</td>
<td>1 (0.612)</td>
<td>3 (0.443)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Orientation</td>
<td>1 (0.518)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Orientation</td>
<td>1 (0.708)</td>
<td>3 (0.353)</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Orientation</td>
<td>1 (0.577)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Orientation</td>
<td>1 (0.610)</td>
<td>3 (0.443)</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Orientation</td>
<td>1 (0.767)</td>
<td>3 (0.469)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Orientation</td>
<td>1 (0.521)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Orientation</td>
<td>1 (0.534)</td>
<td>2 (0.302)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Orientation</td>
<td>1 (0.522)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Form percept.</td>
<td>1 (0.786)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Form percept.</td>
<td>1 (0.842)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q #</th>
<th>Skill tested</th>
<th>Factor 1 (factor loading)</th>
<th>Factor 5 (factor loading)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Form percept.</td>
<td>1 (0.582)</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Form percept.</td>
<td>1 (0.634)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Form percept.</td>
<td>1 (0.674)</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Sequencing</td>
<td>1 (0.799)</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Sequencing</td>
<td>1 (0.681)</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Sequencing</td>
<td>1 (0.739)</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Sequencing</td>
<td>1 (0.834)</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Sequencing</td>
<td>1 (0.876)</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Memory</td>
<td>1 (0.622)</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Memory</td>
<td>1 (0.632)</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Memory</td>
<td>1 (0.467)</td>
<td>5 (0.586)</td>
</tr>
<tr>
<td>34</td>
<td>Memory</td>
<td>1 (0.602)</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Constancy</td>
<td>1 (0.903)</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Constancy</td>
<td>1 (0.845)</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Constancy</td>
<td>1 (0.649)</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Constancy</td>
<td>1 (0.654)</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Constancy</td>
<td>1 (0.763)</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Association</td>
<td>1 (0.931)</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Association</td>
<td>1 (0.701)</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Association</td>
<td>1 (0.829)</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Association</td>
<td>1 (0.809)</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Association</td>
<td>1 (0.756)</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Association</td>
<td>1 (0.592)</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Association</td>
<td>1 (0.773)</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Association</td>
<td>1 (0.767)</td>
<td></td>
</tr>
</tbody>
</table>
Although there are nine factors that have eigenvalues above a value of one (indicated through the Kaiser criterion), there are four main factors that have factor loadings above 0.3 on any of the sets of questions.

Factor one accounts for 43% of the variance, and factors 2-9 account for 25% of the variance. Factors 2-9 could be, however, the random error e in the equation

\[ x = \lambda_n \cdot f_n + e, \]

where n is the number of important factors. This is because although factors 2-9 together account for a considerable proportion of the variation, separately they account for much less than the first factor’s 43% (Factor 2 accounts for 4.9% of the variance—see Table 5.1). The factor loadings seem to point to only one factor, which correlates well with 45 out of 47 questions on the assessment (see Table 5.2). However, factor 2 has factor loadings which are above a 0.3 for all the figure-ground questions 6-10, factor 3 has factor loadings above 0.3 for five out of ten visual orientation questions 11-20, and factor 4 has factor loadings above a 0.3 for four out of five visual discrimination questions 1-5. This evidence for more than one factor is contained in Table 5.3. In this research study the question of one versus more factors must also consider the cronbach’s \( \alpha \) value which is a measure of internal consistency of the test questions, and a measure of the data’s unidimensional nature.

5.3 Reliability:

Cronbach’s \( \alpha \) is a measure of the average of the correlations of all the questions on the VSCS assessment; therefore it measures internal consistency of the items on a scale from 0 to 1. Cronbach’s \( \alpha \) values close to one may be indicative of having only one factor. The
cronbach’s $\alpha$ for the spring semester students’ data was 0.938. If an assessment has Table 5.3: Factor numbers and their factor loadings that are above the cutoff value of 0.3 for the 47 questions on the VSCS assessment tool high internal consistency and is assessing the same skill, then only one factor may be needed to explain the data. The scree plot supported these findings as well. A high cronbach’s $\alpha$ may also indicate redundancy on the items. Several interpretations are possible.

5.4 Possible interpretations

A.) One reasonable interpretation is that only one of the eight visual-perceptual skills is important in explaining the visual-perceptual skills needed on this assessment tool. The data indicates one predominant factor in the scree plot, and a cronbach’s $\alpha$ close to one (0.938) which indicates a unidimensional data analysis. If these results are interpreted as only one of the eight skills being important in the analysis, it would most likely be the visual orientation skill set due to the fact that the Purdue ROT that only tests visual orientation skills had no significant differences to the scores on the VSCS assessment of 26 randomly selected students. However, this is an unlikely conclusion because of the factor loading values obtained. If one set of skills was more important than all the others, this set of questions should have had much higher factor loading values than the others on the first factor because these types of skills would then dominate this factor. This is not the case as almost all the questions have high factor loadings on the first factor.

B.) Since one large factor accounts for 43% of the variance, with other smaller factors having significant factor loadings, a second plausible conclusion is that there is one predominant factor and the rest of the other skills are hidden by the largest factor. This factor
could be a general visual-perceptual skill needed to solve all the questions that was not considered in the theoretical framework chosen. For example, a skill such as depth perception, which is defined as the ability of an observer to judge the spatial relationships of objects, might be needed to solve all the questions but was not considered in the theoretical framework of Rochford and Archer. This interpretation could also mean that other skills are involved, but hidden by the one overbearing main factor. This is postulated because some of the question sets that were representing specific skills were described by multiple factors.

For example, visual discrimination questions 1-5 had four out of five questions associate with factor 4, visual figure-ground questions 6-10 associated with factor 2, and visual orientation questions 11-20 had five out of ten questions associate with factor 3. (See Table 5.3 for this data)

C.) The visual discrimination, visual figure-ground, and visual orientation skills’ questions had their own factors that describe them but this is not the case with the other skill sets. This result along with the strong evidence for unidimensional data may indicate that the questions on the VSCS can not adequately segregate all pertinent skills. This could be because the skills themselves are not able to be separated or that the questions chosen cannot isolate a particular skill set. Figure 5.2 summarizes viable interpretations for the results obtained in this study.
5.5 Differences among students:

The Visual-Spatial Chemistry Specific test given in the spring semester contained opinion statements regarding the amount of time and effort exerted by the students on the assessment. These opinion statements were asked on a five-point Likert scale with 1 being “strongly disagree” and 5 as “strongly agree”. The statements were, “I put a lot of effort into this assignment” and “I put a lot of time into this assignment”. The categorical question asked students how many semesters of organic chemistry they had completed. It was hypothesized that students who have had more organic chemistry courses and who put more
time and effort into this assessment would do better. A table of p-values from the ANOVA analysis of these data is included in Table 5.4.

Table 5.4: p-values about correlations between student score and categorical and opinion questions.

<table>
<thead>
<tr>
<th>Question</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many semesters of organic chemistry have you completed?</td>
<td>0.5194</td>
</tr>
<tr>
<td>How much effort did you put into this assignment?</td>
<td>0.1195</td>
</tr>
<tr>
<td>How much time did you spend on this assignment?</td>
<td>0.0642</td>
</tr>
</tbody>
</table>

The data shows that there were no significant differences as all the p-values were above the $\alpha$ value of 0.05 for a 95% significance level. In other words, none of these questions seemed to significantly influence the overall score of the students who took the VSCS assessment.

The VSCS assessment was given to 816 students in 5 different chemistry courses and 7 different classes. Table 5.5 contains a breakdown of these students’ classes, the number of students in each class, the mean score, and the standard deviation on the VSCS assessment tool of the class.

Table 5.5: Number of students taking the Visual-Spatial Chemistry Specific assessment, their mean score, and standard deviation

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of students</th>
<th>Mean Score</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Chemistry (101)</td>
<td>228</td>
<td>27.33</td>
<td>11.61</td>
</tr>
<tr>
<td>Organic I (221) -004</td>
<td>47</td>
<td>26.18</td>
<td>12.84</td>
</tr>
<tr>
<td>Organic I (221) -002</td>
<td>139</td>
<td>31.36</td>
<td>7.21</td>
</tr>
<tr>
<td>Organic I (221) -003</td>
<td>131</td>
<td>28.44</td>
<td>11.60</td>
</tr>
<tr>
<td>Organic II (223)</td>
<td>175</td>
<td>24.44</td>
<td>12.07</td>
</tr>
<tr>
<td>Physical Chemistry (331)</td>
<td>60</td>
<td>29.50</td>
<td>9.22</td>
</tr>
<tr>
<td>Inorganic Chemistry (401)</td>
<td>36</td>
<td>36.28</td>
<td>5.76</td>
</tr>
<tr>
<td>Total</td>
<td>816</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Differences in mean student scores corresponding to the level of the chemistry course involved were expected. It was assumed that students in more advanced chemistry courses (such as Organic II, Physical, and Inorganic chemistry classes) would have higher scores
than students in the less advanced chemistry courses (Organic I and General). This was hypothesized because as students progress in their chemistry studies, they should utilize more advanced visual-perceptual skills, hence their score on an assessment measuring visual-perceptual skills should increase as well. This analysis was done using the non-parametric Kruskal-Wallis technique, since the assumptions of normality and equal variance from the individual class data were violated. Also, since there were seven comparisons being done, the Bonferroni correction was employed to solve the problem of giving significance to comparisons that are not significant, a type II error. The new $\alpha$ value to determine significant differences is 0.00232. The data from this analysis is given in Table 5.6.

Table 5.6: Differences in student score per class, expressed as p-values. (* = significantly different mean scores)

<table>
<thead>
<tr>
<th>Class</th>
<th>General</th>
<th>Org I – 2</th>
<th>Org I – 3</th>
<th>Org I – 4</th>
<th>Org II</th>
<th>Physical</th>
<th>Inorganic</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Org I – 2</td>
<td>&lt;.0001*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Org I – 3</td>
<td>.0563</td>
<td>.1900</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Org I – 4</td>
<td>.9821</td>
<td>.0228</td>
<td>.2401</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Org II</td>
<td>.0733</td>
<td>&lt;.0001*</td>
<td>.0006*</td>
<td>.2764</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>.0772</td>
<td>.2566</td>
<td>.9798</td>
<td>.2269</td>
<td>.0024</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Inorganic</td>
<td>&lt;.0001*</td>
<td>.0008*</td>
<td>.0002*</td>
<td>.0001*</td>
<td>&lt;.0001*</td>
<td>.0002*</td>
<td>-</td>
</tr>
</tbody>
</table>

It can be observed that the Inorganic class had statistically significant different scores from the other chemistry classes. It must be noted that the Inorganic class was the only class where chemistry majors represented the majority of the students (59%). The breakdown of the different majors from the classes shown in Table 5.7 included the most popular majors, with the “Other” as the category with a great variety of majors.
Table 5.7: Percentages of different majors from seven different chemistry classes from the Spring semester 2008

<table>
<thead>
<tr>
<th>Major</th>
<th>Chemistry</th>
<th>Biological science</th>
<th>Engineering</th>
<th>Biochemistry</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>2</td>
<td>22</td>
<td>11</td>
<td>&lt;1</td>
<td>65</td>
</tr>
<tr>
<td>Organic I -2</td>
<td>7</td>
<td>27</td>
<td>18</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Organic I -3</td>
<td>4</td>
<td>24</td>
<td>7</td>
<td>13</td>
<td>52</td>
</tr>
<tr>
<td>Organic I -4</td>
<td>23</td>
<td>40</td>
<td>6</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Organic II</td>
<td>6</td>
<td>32</td>
<td>14</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>Physical</td>
<td>11</td>
<td>3</td>
<td>2</td>
<td>63</td>
<td>21</td>
</tr>
<tr>
<td>Inorganic</td>
<td>59</td>
<td>&lt;1</td>
<td>13</td>
<td>13</td>
<td>15</td>
</tr>
</tbody>
</table>

The assumption has been that students’ make progress in their visual-perceptual skills during their undergraduate chemistry studies. However, the opposing assumption may well be that chemistry majors already have developed visual-perceptual skills before they enter college and they do not expand on them during their college years. This was investigated by analyzing the data from the chemistry majors only in the three classes where there were sufficient numbers of chemistry students—Organic I (3 sections) (n=26), Organic II (n=11), and Inorganic chemistry (n=21). The raw mean scores and the results of the non-parametric Kruskal-Wallis analyses are in Table 5.8.

Table 5.8: Raw mean scores and the comparison of those scores with the associated p-value

<table>
<thead>
<tr>
<th>Classes</th>
<th>Raw mean scores</th>
<th>Comparison</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic I</td>
<td>30.6</td>
<td>Organic I and Organic II</td>
<td>.7649</td>
</tr>
<tr>
<td>Organic II</td>
<td>25.3</td>
<td>Organic II and Inorganic</td>
<td>.0831</td>
</tr>
<tr>
<td>Inorganic</td>
<td>36.5</td>
<td>Inorganic and Organic I</td>
<td>.1972</td>
</tr>
</tbody>
</table>

As can be seen by the comparisons in this table, there is no significant difference in the scores of the chemistry majors in the different classes. This could imply that students who are chemistry majors already have developed their visual-perceptual skills and no improvement occurs during their college studies. However, research studies have shown that visual-perceptual skills can be taught. In Talley’s study, models were used in
chemistry classrooms and spatial tests were given. Small and Morton’s research paper involved organic students completing visualization workbooks and final grades were compared to students who just got nomenclature help. In Lord’s research, visual-spatial exercises were used with biology students. In Pilburn’s et al. research study, specialized geology computer programs were used to help promote students visual-perceptual skill growth. All these research studies indicated that visualization skills could be taught to science students. Another possible interpretation for the results is that the chemistry classes as taught at North Carolina State University are not promoting visual-perceptual skill growth, so the students’ skills do not change or mature as they progress towards more advanced courses.

5.6 References:


Chapter 6. Conclusions and Future Work:

6.1 Validity:

Content validity of the Visual-Spatial Chemistry Specific (VSCS) test was satisfied as the assessment tool was based on a theoretical framework of eight visual-perceptual skills proposed by Rochford and Archer. From our results it is apparent that the VSCS assessment tool is reliable (Cronbach’s $\alpha = 0.938$), and that the concurrent validity is upheld since no significant differences between the scores on the VSCS assessment and the Purdue Rotation of Visualization test (Purdue ROT) were found.

Failure to reject the statistical null hypothesis of a difference between the scores of the Visual-Spatial Chemistry Specific tool plus the ten visual orientation questions and the validated Purdue Rotation of Visualization Test (ROT) indicates that the VSCS assessment has concurrent validity. Both $p$-values for the comparison of the whole VSCS tool and the 10 visual orientation questions on the VSCS assessment to the Purdue ROT are greater than 0.05. These results combined with the fact that the Purdue ROT only tests visual orientation skills could mean that the rotating and reflecting skills are the primary skills students are using to solve the VSCS assessment in its entirety, however as discussed in section 5.4 the factor loading values challenge this interpretation.

The research hypothesis that there would be eight factors corresponding to the eight visual-perceptual skills of the theoretical framework was shown to be inaccurate. Factor analysis on the data discovered one predominant factor with the scree plot in Figure 5.1 and a high Cronbach’s $\alpha$ value of 0.938 supporting this conclusion. There are also several smaller but contributing factors that correspond to visual discrimination, visual figure-ground, and
visual orientation skills. The best explanation of the one predominant factor is that it is a skill not considered in the theoretical framework, such as depth perception. This conclusion is supported by the data that show a) the one main factor did not have high factor loading values on any specific skill, b) the first factor had high factor loadings on almost all the questions, and c) the most important skill was not one of the eight theorized visual-perceptual skills. Consequently, the questions themselves are unable to discriminate between the different visual-perceptual skills. A more rigorous analysis of the questions themselves should be conducted. Relevant visual-perceptual skills might be hidden by the one main factor, and the skills which were dominant (discrimination, figure-ground, and orientation) did show up as other factors with statistically significant factor loadings. The test should be redesigned around a new theoretical framework, and retested with a fresh population of students in chemistry classes at North Carolina State University.

6.2 Drawbacks to testing format:

Webassign is mainly a homework distribution tool. The Visual-Spatial Chemistry Specific assessment was assigned as a homework assignment and no students took the VSCS as a test. Instead, the students were given a week to work on the assignment which presents some issues. The Purdue Rotation of Visualization test is a paper and pencil test given for 10 minutes to reduce the amount of analytic reasoning, or reasoning done by breaking apart the diagrams and doing a trial and error type analysis. In addition, students could do the assessment wherever they wanted and that could lead to some cheating. Although the answers are randomized, the questions are not and the answers can be transposed from one student’s assignment to another. As the VSCS was not a common assignment about half of
the professors gave it as extra credit towards the end of the semester. Most of the students who did do it for extra credit did quite well, but there were a few students who did not complete the assessment.

6.3 Other student differences:

The hypothesis that students’ self-reported time and effort were affecting their scores was shown to be incorrect since there were no statistically significant differences between the students’ responses for the questions asked and student scores. (See Table 5.4) A possible interpretation is that chemistry visual-perceptual skills are inherent to an individual, and the time spent, effort expended, and exposure to them has no bearing on developing visual-perceptual skills, although this does not necessarily mean that visual-perceptual skills can not be taught to chemistry students. Two possible causes for a student to have low visual-perceptual skills could be having little exposure to these skills, or not having motivation to do an assessment of this type. If either of these possibilities is true, the students could benefit from an intervention where a specific visual-perceptual skill is targeted and the connection between the skill and intervention is investigated. Future work should encompass interventions and their implementation to discover if visual-perceptual skills can be promoted during a semester of chemistry or throughout an academic career.

The most interesting finding of this research study was that the only class that had significantly higher scores on the Visual-Spatial Chemistry Specific assessment was the inorganic chemistry class. This class had the highest proportion of chemistry majors, 59%, in contrast to the 23% in Organic I (the next highest percentage of chemistry majors). (See Table 5.7) This could be interpreted as: a) chemistry majors have inherently better visual-
perceptual skills than the other science majors seen in this study, or b) students became chemistry majors because of their inherently superior visual-perceptual skills. Both of these interpretations of the data come from the implication that chemistry students have developed their visual-perceptual skills and no improvement occurs during college. The first of these interpretations is flawed, since there were a number of chemical engineering students in the study (14% in the Organic II chemistry class) who have to take basic engineering classes which have been shown to improve visual-perceptual skills,\(^2\) so there is no reason why their skills should not be as advanced as chemistry students. (Unfortunately there were not enough chemical engineering students in each class to do a statistically accurate comparison among them.) The second interpretation is an assumption, because although students tend to migrate toward study areas that are achievable, there has been no research on visual-perceptual skills influencing college majors. A third interpretation is that chemistry classes as taught at North Carolina State University are not promoting visual-perceptual skill growth, so students do not grow in their visual-perceptual skills. The inorganic class can be assumed to be a very visual class, where the students need and practice these skills to succeed in this course.

Rochford theorized that we should screen students for science majors by giving them a test of visual-spatial skills.\(^3\) “Many special fields have recognized that further testing is necessary in the selection of students. Such precautionary measures…have not been employed in the screening of science majors. This is not due to negligence on the part of science educators but, most likely, the consequence of the absence of a suitable instrument for such testing”.\(^4\) The VSCS assessment could be used to help students even before they enter college to assess their strengths and weaknesses in the visual-spatial field. This way the
students and their professors can seek help to try to rectify the students' deficiencies with respect to these skills. Advisors of science majors should be informed of the importance of visual-perceptual skills including research supporting the importance of visual-perceptual skills in a number of science fields: chemistry, biology, geology, engineering, anatomy, and astronomy. Advisors of science students would then be ready to assist students with their visual-perceptual backgrounds.

6.4 Essential visual-perceptual skills:

In this thesis, it is hypothesized that chemistry students need eight visual-perceptual skills, and the first reason why this was hypothesized is because the definitions of the skills fit into a chemistry framework. These eight skills have been discussed in Section 4.

It has been argued in many sources and research studies about what are the essential skills to visual-perceptual problem-solving ability. Thurstone supported one skill, a combination of 3-D and 2-D viewing skills as a result of his factor analysis on different tests and assessment tools. Smith’s book about visual-spatial tests contended that two skills are important, spatial orientation and visualization, and still others have indicated that three skills are important, including spatial orientation, visualization, and kinesthetic imagery. These three skills are physical visual-spatial skills that were hypothesized by reanalyzing Thurstone’s data. For example the kinesthetic imagery skills is defined as “a left-right discrimination with respect to the location of the human body...” More recent meta-analyses done on the topic of gender differences in visual-spatial tests have indicated that three spatial abilities are important: spatial perception, spatial visualization, and mental rotation. These mental visual-spatial skills are defined in terms of abilities to rotate or
manipulate objects. Psychologists and educators are arguing over how many essential visual-perceptual skills are needed. It would appear from this research study that one essential visual-perceptual skill is needed for chemistry students to solve visual-spatial type questions, but more research still needs to be done in this important area of research. The question still remains on how to accurately assess these specific skills for chemistry students.

The data from this study show that the factor pattern of the results is ambiguous. There are several different explanations, including that the skills can not be separated by the specific questions asked on the Visual-Spatial Chemistry Specific assessment, or that only one factor, a general skill not considered in VSCS assessment’s theoretical framework, is involved. The data appear to suggest that the chemistry classes as taught at North Carolina State University are not promoting visual-perceptual skill growth, so the students’ skills do not mature. These results show the complexity of assessing visual-perceptual skills as they are not just a simple set of skills, but instead a wide and varied set of skills. The Visual-Spatial Chemistry Specific (VSCS) tool will open discussion with instructors and students, in terms of how students learn chemistry and the best ways to teach these courses. This is ultimately the goal of any chemistry assessment research.

6.5 References:


Chapter 7. Appendix
Appendix I: The Complete Visual-Spatial Chemistry Specific Assessment Tool (As printed from Webassign)
Visual-spatial assessment (499292)

Instructions
Answer each question only if you can see a picture associated with it. This assessment is meant to evaluate 8 visual-perceptual skills. For questions with pictures as possible answers - the circles for your choices are to the left side of the pictures. The first 3 questions of this assignment are category questions. The last 4 questions of this assignment are meant to gauge your effort, time, and opinion of this assessment. Thank you very much for your help.
If you have any questions about this assignment please e-mail Caroline at cmchrist@ncsu.edu
Hint: Use a model kit or a piece of paper to draw your ideas down.

1. IRB question [847998]
I affirm that I am cmchrist@ncsu. I give permission for my test scores to be used without my name attached to them, for research purposes only.
☐ I agree

2. Visual-spatialcategory#1 [847993]
How many semesters of organic chemistry have you completed?

3. visual-spatialcategory#2 [847995]
What is your major?

4. visualspatialassessment#1 [749886]
In the next five questions, the framework of a wire figure is drawn on the left. On the right are three diagrams suggesting how this hollow wire model might appear when viewed from a different angle. In each case either all three diagrams are possible views or only two of the diagrams are possible and one drawing could never be observed no matter what your angle of view. Pick either the number of the diagram which could never be observed, or if all of them could be observed, pick number "4".

1 2 3 4 All of these could be observed
5. visualspatialassessment #2 [746341]

Pick the number of the diagram which could never be observed, or if all of them could be observed, pick number “4”.

6. visualspatialassessment #3 [749900]

Pick the number of the diagram which could never be observed, or if all of them could be observed, pick number “4”.

7. visualspatialassessment #4 [749901]

Pick the number of the diagram which could never be observed, or if all of them could be observed, pick number “4”.

8. VisualSpatialAssessment#5 [749902]

Pick the number of the diagram which could never be observed, or if all of them could be observed, pick number "4".

9. VisualSpatialAssessment#6 [750424]

The diagram below is an illustration of the structure of diamond. Each lettered black dot represents an atom of carbon. For each question choose the one best response.
Atom letter S lies on the same outside vertical plane as atom letter E, Q, R, or U?

Atom letter M lies in the same horizontal plane as atom letter Q, R, S, or U?

Atom letter Q lies in the same vertical plane as atom letter H, P, T, or R?

Atom letter U lies in the same horizontal plane as atom letter K, L, N, or T?

Look at atom letter U; it is attached to 4 other atoms H, J, L, R. Look at atom letter H; it is only attached to 2 other atoms U and T. It should be attached to 4 atoms. Should atom H's other two atoms it is attached to be outside the cube or inside the cube?

Type either inside or outside.

10. visualspatialassessment#11 [750495]

Use these axes for questions 10 - 14.

If the structure in diagram 1 were rotated about the Y-axis around the above axes 180 degrees, which diagram below would represent the structure as seen after rotation?
11. VisualSpatialAssessment#12 [750581]

If the structure in diagram 1 were rotated about the Y-axis around the above axes more than 180 degrees, which diagram below would represent the structure as seen after rotation?
12. visualspatialassessment\#13 [750562]

If the structure in diagram 1 were rotated about the Z-axis around the above axes less than 90 degrees, which diagram below would represent the structure as seen after rotation?
If the structure in diagram 1 were rotated about the **Z-axis** around the above axes less than 90 degrees, which diagram below would represent the structure as seen after rotation?

![Diagram 1](image)

14. **visuaspatialassessments#15** [750659]

If the structure in diagram 1 were rotated about the **X-axis** around the above axes 90 degrees, which diagram below would represent the structure as seen after rotation?

![Diagram 2](image)
15. *visualspatialassessment#19 [751425]*

Among the molecular representations below, pick which one you would get after reflecting molecule A with the marked mirror.

![Molecule A](image)

16. *visualspatialassessment#20 [751427]*

Among the molecular representations below, pick which one you would get after reflecting molecule A with the marked mirror.
17. visual spatial assessment #16 [751416]

Note: The X- and Y- axes are drawn in the plane of the paper. Imagine the Z-axis as being perpendicular to them, coming out of the screen.

The letters on the molecules refer to atom identity.

This is an example problem:

Imagine you are standing in front of this structure:

```
A
```

1. To do this problem if this structure were reflected in the XY-plane, imagine a mirror in the XY-plane, and the answer would be:

```
A
```

This is the real problem:

Imagine you are standing in front of the structure in diagram 1. If the structure in diagram 1 were reflected in the XY-plane, imagine a mirror in the XY-plane, and the answer would be:

```
A
```
which diagram below could represent the structure as seen after reflection?

![Diagram 1](image)

18. visualspatialassessment#17 [751417]

Note: The X- and Y- axes are drawn in the plane of the paper. Imagine the Z-axis as being perpendicular to them, coming out of the screen.

Imagine you are looking at the structure in figure 1 from the front. If the structure in diagram 1 were reflected in the XZ-plane which diagram below could represent the structure as seen after reflection?

![Diagram 1](image)

19. visualspatialassessment#18 [751418]
Note: The X- and Y- axes are drawn in the plane of the paper. Imagine the Z-axis as being perpendicular to them, coming out of the screen.

Imagine you are looking at the structure in diagram 1 from the front. If the structure in diagram 1 were reflected in the YZ-plane which diagram below could represent the structure as seen after reflection?

Diagram 1

For questions 20-24, if the answer is more than one number, type the numbers in numerical order with commas and no spaces. For example 1,2,3 An answer of 2,3,1 is not correct because they are not in numerical order. If the answer is a word, type the word in just like the word is written in the question.

The diagram below is a stereochromical representation of a molecule of ethanol. In this diagram indicates that a bond projects behind the screen, and indicates that a bond projects out of the screen towards you. Atoms that are connected with straight lines indicate that the bond is in the plane of the paper.

The atom(s) in the model which is (are) closest to your eyes

The atom(s) in the model which is (are) furthest from your eyes

4,9

5,8
21. visualspatialassessment#23 [751473]
The diagrams below are a ball and stick representation of a molecule of n-butane

The carbon atoms are labeled 1 thru 4. The carbon atom in the model which is closest to your eyes is carbon atom number 4.

22. visualspatialassessment#24 [751474]

The hydrogen atoms are labeled 1 thru 4. The hydrogen atom which is furthest back from your eyes is hydrogen atom number 1.

23. visualspatialassessment#25 [751475]
The diagram below is a ball and stick representation of a molecule of isobutane.
The hydrogen atom which is farthest from the hydrogen atom labeled "H" is hydrogen atom number 1.

24. visualspatialassessment#26 [751476]

For this question, if the answer is more than one number, type the numbers in numerical order with commas and no spaces. For example 1,2,3. An answer of 2,3,1 is not correct because they are not in numerical order. If the answer is a word, type the word in just like the word is written in the question.

The diagram below illustrates the regular crystal lattice structure of zinc sulfide. The positioned black dots represent ions of zinc; sulfide ions are represented in their positions by the numbered white circles. There are 18 atoms represented in this unit cell of Zn-S.

View the top face of the box that represents these unit cells. Which atoms are on this face?

View the atom labeled 8. Is atom number 2 above or below atom 8? below.

Which atom(s) are not connected to any others by solid black lines?

View the right face of the box that represents these unit cells. Which atoms are on this face?

View the atom labeled 2. Which atoms are connected to this atom?

25. visualspatialassessment#31 [751588]

In the next four questions four different diagrams of the given molecule are presented, suggesting how the molecule would appear when viewed from different angles. In each case, three of the four diagrams are of the same molecule, whereas one of the four diagrams is incorrect because it shows a mirror image of the molecule. For example and
Two different types of models of organic molecules are illustrated below: SPACE FILLING models and BALL-AND-STICK models. Space filling models more closely resemble the actual shape of the molecule as the electron clouds are represented. Ball-and-stick representations with elongated bond lengths show more clearly how one atom is connected to the next.

In the next five questions, you are provided with a ball-and-stick model of an organic molecule. Set out below it are four diagrams of space-filling models of organic molecules. The models may be rotated in any direction. Pick the space-filling model that matches the ball-and-stick model.
34. visualspatialassessment#41 [751628]

For questions 34 to 37 refer to the diagrams that are associated with each question. These diagrams are pictures of three-dimensional unit cells that are represented by cubes or spheres that have been stacked on one another.

![Front side](image1)

How many unit cubes are needed to fill the hollow part of the structure in the middle?

How many unit cubes are in this structure, considering the hollow part in the middle to be one unit?

35. visualspatialassessment#43 [751630]
How many cubes are in this structure? 27
How many cubes are inside and have no face visible on the outer surface? 1

36. visualspatialassessment#44 [751633]
For this unit cell, answer the following questions.

How many spheres are in this structure? 36
Consider a sphere on the inside, how many other spheres will touch it? 6

37. visualspatialassessment#45 [751635]

How many spheres are in this structure? 14
How many spheres are in the middle horizontal layer? 4

38. Likertscale#1 [848932]
Answer the next three questions on a scale from 1-5:
I put a lot of effort into this assignment.
- 1= Strongly disagree,
- 2= Disagree,
- 3= Neither agree nor disagree,
- 4= Agree,
- 5= Strongly agree.

39. Likertscale#2 [848933]
I put a lot of time into this assignment.
- 1= Strongly disagree,
- 2= Disagree,
- 3= Neither agree nor disagree,
- 4= Agree,
- 5= Strongly agree.

40. Likertscale#3 [848934]
The quality of instructions on this assignment were high.
- 1= Strongly disagree,
- 2= Disagree,
- 3= Neither agree nor disagree,
- 4= Agree,
- 5= Strongly agree.

41. Opinionquestion#3 [849408]
Do you have any comments or concerns about this assessment?

Key: Answer