EXAMINING THE SPATIAL ABILITY PHENOMENON FROM THE STUDENT'S PERSPECTIVE

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DEDICATION

To my wife, Lisa—for her steadfast love and support of all that I do.

To my parents—for starting me down this academic road.

ACKNOWLEDGMENTS

There are many who have supported the creation of this work, making it difficult to choose the words that truly express the heartfelt gratitude and appreciation I feel. Words at times do not seem to carry the full import. Nevertheless, I would like to begin by thanking the members of my committee for their guidance, suggestions, criticisms, and support. As my chair, Dr. Timothy Newby has been quite patient with me as I have traversed a somewhat "non-traditional" path in the pursuit of this degree and the completion of this work. His continued encouragement and advice have been invaluable. To Drs. James Lehman and Ala Samarapungavan I extend gratitude for their timely reviews and thoughtful insights during the creation of this document and the execution of this project. To Dr. Craig Miller, for his continued "encouragement" to make the time to get this done (which at times made me love and hate him like a brother), I am grateful. And, to Dr. Donna Enersen, who late in this project was willing to jump on-board and provide critical expertise in qualitative research, I am equally thankful.

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Finally, to my greatest supporter, my greatest advocate, and my best friend, I thank my wife Lisa for listening to countless hours of frustration, belabored discussions about "phenomenology" and explanations thereof, and for cheering.

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ABSTRACT

Mohler, James L. Ph.D., Purdue University, August, 2006. Examining the Spatial Ability Phenomenon from the Student's Perspective. Major Professor: Tim J. Newby.

Using the phenomenological approach, this investigation examined the lived experience of technically-oriented students over the course of a single semester, attempting to answer the question, "What was it like for a student to experience the spatial ability phenomenon?" Participants in the study included 12 interviewees and 8 focus group participants from a freshman engineering graphics course at a Midwestern university. Based upon the analysis of data from interviews, observations, applied tasks, and focus groups, five invariant themes were elicited. These included common background and experiences of participants, characteristics or tendencies of those who were high and low spatial ability, common errors made in spatial sketching tasks, approaches and processes relative to spatial problem solving activities, and feelings that were expressed or observed in the participants relative to spatial tasks. Outcomes of the study were the confirmation of effective instructional methods used in the course, the acknowledgement of the importance of object decomposition skills in spatial problem solving, and a systematic process for the generation of isometric pictorials from multiview drawings. This contribution includes a listing of teaching implications and recommendations, as well as suggestions for future qualitative studies on spatial ability.

CHAPTER 1. INTRODUCTION

This chapter provides an overview to this research study and to this document. This chapter establishes significance within the already existing canvas of spatial ability research that is as broad as it is deep. Important also is laying the practical groundwork related to the definition of scope through purpose, research questions, assumptions, and limitations. Finally, this chapter concludes with a brief overview of this project.

1.1. Background

Ever since I began teaching, I have always been curious; what interventions aid in the improvement of spatial ability of students? Watching other faculty and reviewing the related literature, the approaches and the results sometimes seem indiscriminate. Upon further study and when combined with my own classroom experiences, it became clear that spatial ability, while noticeably present or absent as evidenced by student performance, is much harder to define and definitively measure than one would suspect. With an insatiable curiosity and a desire to help my students improve, I set out to learn more and to formulate a research project that would contribute to the overwhelming mass of research that began over 100 years ago.

At a minimum, three interrelated facets comprise spatial ability. They are spatial visualization, spatial relations, and spatial orientation (Lohman, 1979a). While certain researchers may define more than these components in their work, and though the nomenclature may vary, most at least include these three. Visualization is generally defined as the ability to picture an object, process, or other representation within the mind, based upon some other symbolic description—whether that description is graphical, textual, verbal, or symbolic. Spatial relations is the ability to reorient an object in the mind quickly. Spatial orientation is the ability to reorient the vantage of an object mentally by moving the viewpoint.

As it relates to spatial ability, there are many unanswered questions. In engineering, what is it that makes some students able to mentally construct or deconstruct a picture in their mind with exquisite, vivid detail, while others have difficultly constructing such mental images (where even the images that these latter conjure up lack sufficient detail to be of any usefulness)? In programming, why can some programmers cognitively construct the solution to a coding problem—completely understanding its flow, inputs, and outputs from beginning to end—without ever needing to draw flow diagrams, while others struggle to understand the same? Moreover, in the seemingly unrelated area of music, what allows some musicians and composers to read sheet music and envision the auditory flow of a piece without ever touching a musical instrument?

These are but a few questions that, if answered, would help define appropriate interventions for those weak in spatial ability. In many fields, researchers are striving for the same thing: unlocking the secret of spatial ability so that students may be more successful in their chosen field. Much research has been devoted to the use of specific interventions, but none has focused on understanding the individual's perspective and the experience of the phenomenon using a qualitative approach. How would a student describe spatial ability? What would he or she report as inhibitors of this ability? What would he or she say helps exercise spatial ability? What would a student report as relevant experiences, background, or education?

Attempting to answer these questions through student perspectives was the goal of this research. Its purpose was to provide insight into the background, life experiences, and perceptions of specific individuals in relation to spatial activities.

1.2. Significance

Through all the spatial ability literature that has been documented, little attention has been paid to examining specific cases from the qualitative perspective. I believed that by approaching spatial ability phenomenon from the qualitative perspective, I could better understand what high and low spatial ability students perceived when presented with spatial problems. Naturalist inquiry offers a different perspective on spatial visualization research and interventions. Rather than striving to create an intervention and determine its impact, as has been done time and again, this study focused on the students and elicited their thoughts about their own spatial ability. The insights contained in this study should help researchers and teachers who have struggled to determine how to improve those abilities better design, develop, and evaluate spatial ability interventions.

1.3. Statement of Purpose

The purpose of this research was to elicit, describe, and analyze the background, life experiences, and perspectives of individuals with varying levels of spatial ability answering the question, "What was it like for a student to experience the spatial ability phenomenon?" Understanding the student perspective and experience of the spatial ability phenomenon may lead to insights into the potential reasons for strength or weakness in visualization and a greater understanding about appropriate spatial ability interventions.

1.4. Research Questions

The questions central to this research were:

1. What do students report as their personal background (gender, parental occupation, parental involvement, or family income) that could have contributed to their strength or weakness in spatial ability?

2. What personal experiences (hobbies and childhood or teenage experiences) or academic experiences (favorite courses, teachers or subjects) have contributed to their ability or inability?
3. How do students approach spatial activities given their level of spatial ability, that is, what are their attitudes, thought processes, and perceptions surrounding such activities?

1.5. Assumptions

The following assumptions were inherent to the pursuit of this study:

1. There was a need to examine the spatial ability phenomenon from the student's perspective (using a qualitative approach) to gain insight into the essence of spatial ability as exhibited through the lived experience of the student.
2. Participants responded accurately and honestly during the interview process concerning their own experiences, knowledge, and background in the spatial domain.
3. Participants had liberty to acknowledge when they could not answer a question due to lack of knowledge or remembrance.
4. Participants responded accurately and honestly in response to the summary of the interview and in the representation of themes and coding.
5. Participants, to the best of their ability, completed the Vandenberg *Mental Rotations Test*.
6. The number of participants chosen for this study was sufficient for a phenomenological examination of the spatial ability phenomenon.
7. Working with students enrolled in an engineering drawing course elicited opportunity for the students to experience the phenomenon during the period in which the study was conducted.
8. Participants had liberty to acknowledge if they were not cognizant of experiencing or using their spatial ability.

9. Participants were sufficiently able to verbalize their knowledge and experience in the form of answers to the interview questions.
10. Participants were able to attend three 90-minute interviews.
11. Participants were able to attend one 1-hour focus group meeting.
12. The research methods chosen for this study were appropriate to answer the research questions posed.

1.6. Limitations

The following limitations were inherent to the pursuit of this study:

1. This study was limited to the number of volunteer participants available from CGT 163, spring semester 2006, at the West Lafayette, Indiana campus of Purdue University.
2. This study was limited by the amount of cooperation of subjects and their availability.
3. This study was limited by the amount of cooperation of the Computer Graphics Technology Department administration in providing time for the researcher to complete the study.
4. This study was limited by the amount of cooperation of the CGT 163 course director and teaching assistants.
5. This study was limited to the accuracy of the Vandenberg *Mental Rotations Test* accurately in measuring spatial ability spatial ability.

1.7. Delimitations

The following delimitations were inherent to the pursuit of this study:

1. The facilities available at the West Lafayette, Indiana campus of Purdue University.

2. Students enrolled in CGT 163 during the spring 2006 semester at the West Lafayette campus of Purdue University
3. A period of one semester allotted to interact, interview, and engage the participants.

1.8. Definitions of Key Terms

epoché or bracketing – first step in phenomenological data analysis (also called reduction) in which the researcher sets aside all preconceived experiences, as far as is humanly possible, to understand the experiences of participants of the study (Moustakas, 1994).

Horizontalization – second step in the phenomenological data analysis where each statement is listed and given equal value (Moustakas, 1994).

phenomenological study – a study that describes the meaning of experiences of a phenomenon (topic or concept) for several individuals in an effort to capture the central meaning or "essence" of the experience (Moustakas, 1994).

spatial ability – individual differences used in the process of non-linguistic information or individual differences in performance on spatial tests (Eliot & Smith, 1983); the ability to generate, retain, and manipulate abstract visual images (Lohman, 1979a).

spatial cognition – the spatial features, properties, categories, and relations in terms of which we perceive, store, and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations (Olson & Bialystok, 1983).

spatial intelligence – the capacity to perceive the visual world accurately, to perform transformations and modifications upon initial perceptions, and to be able to recreate aspects of visual experience even in the absence of relevant physical stimuli (Gardner, 1984).

spatial relations – ability to determine the relationships between different spatially-arranged stimuli and responses, and the comprehension of the arrangement of elements within a visual stimulus pattern (Guilford & Lacy, 1947).

spatial visualization – ability to imagine the rotation of depicted objects, the folding and unfolding of flat patterns, and the relative changes of position of objects in space (Guilford & Lacy, 1947); the mental ability to manipulate, rotate, twist, or invert pictorially presented visual stimuli (McGee, 1979b).

1.9. Overview of Study

Almost ubiquitously within the spatial ability domain, quantitative research is performed. From an analysis of gender differences to spatial ability interventions, such research has a long quantitative history. However, little attention has been paid to introspectively inquiring of the participants why they are successful or unsuccessful with spatial material. Researchers such as Lohman and Kyllonen (1983) have indicated that the qualitative research approach could add much to the understanding of spatial ability if researchers were to begin using such methods. Therefore, the qualitative research approach seemed to be the best method of answering the questions posed in this research and had the potential to provide a unique contribution to the field.

Each of the questions addressed in this research was intended to reveal the phenomena of spatial ability and its structure through the lived experience of the participants. The goal was to establish plausible explanations for patterns that are seen in high and low visualization ability students—what were the characteristics that cause them to be high or low in this ability, that is, if indeed there were common characteristics—and how might we learn from these patterns to provide instruction in spatial ability improvement? To exemplify this, the differences in lived experiences between those classified as high and low were focused upon. To the extent that the study describes the lived experience of the participants and their experience with the spatial phenomenon is the extent to which the study is inclined toward the phenomenological framework (Patton, 2002).

This research used the tools of qualitative research methodology in the form of interviews, observations, and focus groups. It was founded upon the phenomenological perspective. As a mode of inquiry, phenomenology examines participant experiences and their meanings in the search for understanding of everyday phenomenal experience (Van Manen, 1990). Its primary focus is "to explore how human beings make sense of experience and transform experience into consciousness, both individually and as shared meaning" (Patton, 2002, p. 104). The effectiveness of such studies is based upon how well a study communicates the participant experience and meaning.

1.10. Organization

This dissertation provides six major chapters and several appendices. Chapter 2 provides an overview of spatial ability research. It begins with a brief historical overview and a major section on each psychological research approach that has dealt with spatial ability. The chapter then discusses the importance of spatial ability, the myriad methods for measuring and improving it, and a summary of current points of emphasis.

Chapter 3 provides an overview to the methodology and framework used in this study. The chapter is devoted to detailed discussion of the qualitative methods and phenomenological approach used for this project.

Chapter 4, Findings, provides a detailed explanation of the analysis of data. The following information is described in detail: demographics of the study participants, detailed participant descriptions and background information, researcher epoché, interview results, and the textural and structural descriptions of the data from each participant.

Chapter 5 reports the invariant themes that emerged from the data analysis. The chapter introduces each theme as it emerged for high and low spatial ability participants and provides supporting narratives.

Chapter 6 contains a summary of the document, the conclusions of the study, and discussion of the results and recommendations for further research.

1.11. Summary

This chapter has provided an overview to the research project, including background, significance, purpose, research questions, and scope definitions. The chapter has also concluded with an overview of the study and this document. The next chapter outlines the history of spatial ability research including major periods and research foci, importance and measurement of spatial ability, methods for improving spatial ability, as well as current and future directions of the area.

CHAPTER 2. REVIEW OF RELEVENT LITERATURE

Research concerning spatial ability has a long history. As early as 1880, Sir Francis Galton reported on his inquiries into mental imagery. Since that time, researchers have defined spatial ability in numerous ways, contended over its constituents, and created various methods for measuring it. Today, spatial ability continues to be an active thread of research found throughout many disciplines.

This chapter provides an overview of spatial ability research. The opening section provides a brief historical overview and a major section on each psychological research approach that has dealt with spatial ability. The chapter then discusses the importance of spatial ability, the myriad methods for measuring and improving it, and a summary of current points of emphasis.

2.1. Approach to This Review

The breadth and depth of literature related to spatial ability is daunting. As any beginning researcher in this area, I started with familiar threads but quickly found an incredible mass of material ranging from historical to practical to theoretical. Indeed, spatial ability research and practice has touched nearly every field and domain, making a simple summation of the literature difficult at best. In my search, I chose to siphon specific details (rather than delving too deeply in one thread or topic) so as to provide a holistic view of the entire area. Critics may contend that I have omitted highly important details. This may be true in some instances. However, in an effort to provide breadth of coverage and maintain a manageable manuscript length, this is the approach I have selected. My goal in this was to provide a chapter that can serve as a primary starting point for study by future students; providing primary discussion of what I believe are seminal articles in this area with reference to peripheral topics or branching themes.

2.2. The History of Spatial Ability Research

It seems appropriate to open this review of literature with a brief section on the history of spatial ability research. One may review other works that provide historical accounts with varying levels of detail (Carroll, 1993; Eliot & Smith, 1983; McGee, 1979b; Smith, 1964). The following section will provide a brief highlight of that history, touching on the major themes and contributions to the field as a whole.

Publications with a primary focus on spatial ability did not begin to emerge until the early 1920s. The early research (1880-1940) focused on defining spatial ability as separate from general intelligence. Through the work of Thorndike (1921), Kelley (1928), El Koussy (1935), and Thurstone (1938), spatial ability was acknowledged as a separate capacity from the general intelligence factor defined by Spearman (1927). This early research used a psychometric approach (Pellegrino, Alderton, & Shute, 1984), which is typified by "a set of statistical techniques [factor analysis] developed to determine the number and nature of underlying intelligence or personality factors that account for a given set of performance measures" (Cooper & Mumaw, 1985, p.68).

However, while spatial ability gained some attention it was not widely highlighted as important and was often deemed a lesser ability. During WWII, spatial ability testing obtained an important foothold due to large-scale testing conducted in the Army Air Forces (Guilford & Lacy, 1947; Guilford & Zimmerman, 1947a). During the period of 1940 to 1960, researchers focused most of their energies on defining what comprised spatial ability. Early research acknowledged a single space factor, whereas subsequent research determined that it was not a unitary ability. This period of research activity led to a better understanding of the factors that comprise spatial ability.

However, there was much confusion amongst the research community (D’Oliveira, 2004; Lohman, 1979a). Different factor names, numbers of factors, and definitions for them ensued due to varying technical implementations of factor analysis techniques and due to the use of different spatial ability tests in type and number (Cooper & Mumaw, 1985). From this period of research, it was generally agreed that spatial ability was not unitary. As well, many spatial tests emerged (see Smith & Eliot, 1983).

The period of 1960 to 1980 saw several divergent threads of research materialize. While psychometric studies continued, developmental studies and differential studies became focal points. Psychometric studies, through work of Witkin (1949, 1950) and Gardner (1953, 1957), examined various cognitive issues such as learning styles. Developmental studies examined how spatial ability develops through childhood to adulthood. Piaget and Inhelder’s work (1967, 1971) has created much interest in this area. Meanwhile, the differential research focused on areas of difference in spatial ability, particularly as it relates to differences across gender, but also as it relates to other attributes. Work by Maccoby and Jacklin (1974) serves as the much-referenced starting point in this area.

Finally, the period of 1980 to today has continued the prior research themes, but has specifically examined the impact of technology on measurement, examination, and improvement of spatial ability. In addition, much attention has been turned toward understanding spatial ability from an information processing standpoint, defining processing models that can theoretically describe it.

One thing remains clear because of this 100-year history of research: spatial ability is a set of complex, cognitive abilities about which there are still many questions. The next major section will review the relationship between spatial ability and general intelligence as defined by psychometric researchers. Subsequent sections will touch on each major research thread, including developmental, differential, and information processing research.

2.3. Psychometric Research

As noted, one of the first challenges posed to the area of spatial ability research was distinguishing it from the general intelligence factor, defined as "g." Intelligence research was pursued by two major groups with differing views. Research in Britain followed Spearman in focusing wholly on intelligence as a single factor, whereas research in the U.S. viewed intelligence as composed of multiple factors. The former work was pursued by Spearman (1904, 1927), Burt (1949) and Vernon (1950) and the latter work was conducted by Thurstone (1938, 1944, 1950), Cattell (1971), and Guilford (1956, 1959, 1967).

Initially researchers had difficulty distinguishing spatial ability factors from intelligence (g) because several of the spatial factors load quite heavily on general intelligence (spatial visualization tests, for example). As a factor of intelligence, it is beneficial to review its relationship, as understood today, with general intelligence. Typically intelligence has been viewed hierarchically and taxonometrically, with the former emerging first (Gustafsson, 1988). Figure 2.1 shows a basic hierarchical view of the structure of human abilities (Smith, 1964).

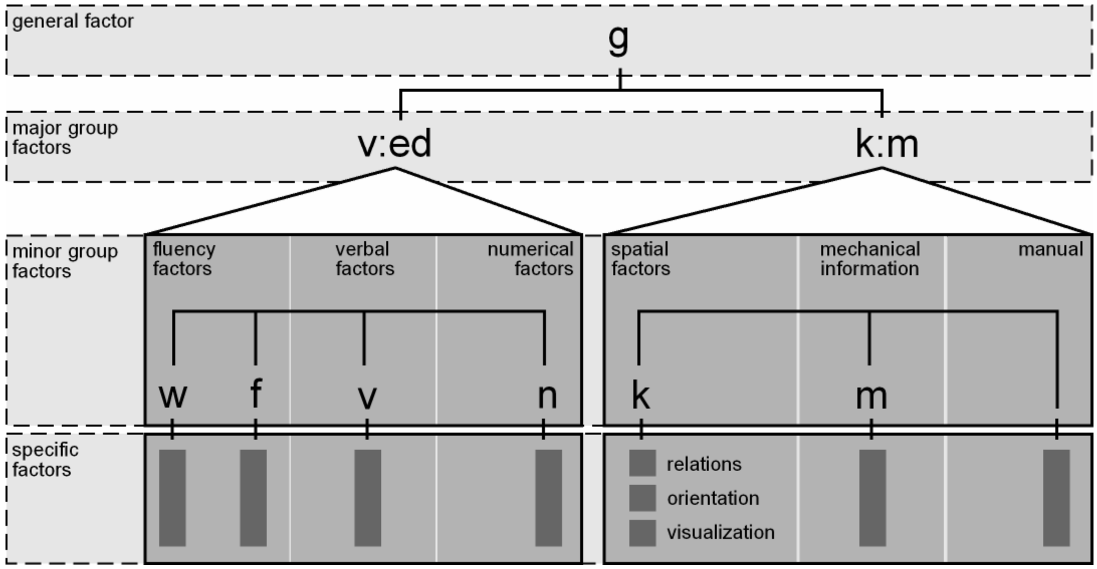

Figure 2.1. Hierarchical structure of human abilities (Smith, 1964).

As shown in Figure 2.1, when mental tests are analyzed using factor analysis, the first factor to be extracted typically corresponds to g. Once g is removed, the tests typically fall into two groups: verbal-numerical (v:ed factor) and the spatial-mechanical-practical (k:m factor). If there are enough tests in the battery being used, the two subgroups can be divided further into minor factors, such as verbal, numerical, or spatial and manual.

Scientific and empirical work that is more recent has attempted to define hierarchical models of intelligence and specific aspects of those models (Carroll, 1993; Jensen, 1998; Snow & Lohman, 1989; Snow, Kyllonen, & Marshalek, 1984). Due to its extensive inclusion of datasets, the best-known contemporary factor analytic survey is Carroll (1993).

Of importance to this review was Carroll's discussion of a hierarchical "three-stratum theory" of ability that "could be accommodated within, or show correspondences with, radex theories that assume hierarchical structures" (Carroll, 1993, p. 654). Carroll identified three hierarchical strata (narrow, broad, and general) into which cognitive abilities fell. Radex theories, the earliest of which Carroll credits to Guttman (1954), are typically taxonomic (rather than hierarchical). Figure 2.2 shows an example of the radex model of intelligence, which demonstrates the positioning of spatial ability in juxtaposition with verbal and mathematical ability.

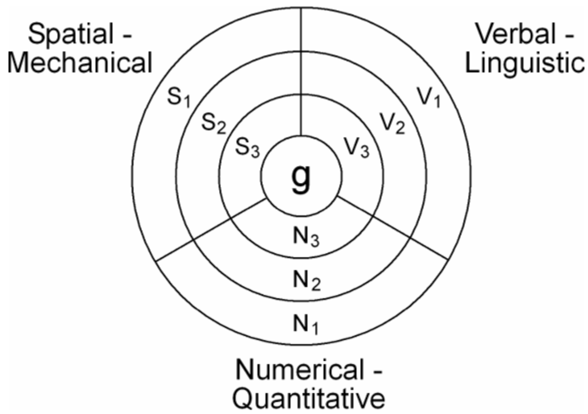

Figure 2.2. Example of the radex model of intelligence (Guttman, 1954).

The three abilities shown in Figure 2.2 have psychological importance and can predict occupational and educational success. While Carroll (1993) discussed arguments against this "three-stratum theory," the sheer magnitude of the data and subsequent studies present a compelling argument for support of the radex model. However, some research acknowledges that hierarchical and radex models can mesh quite well and even complement each other (Snow, et. al, 1984; Snow & Lohman, 1984; Webb, 2005). Several other sources discuss the radex model also (Jensen, 1998; Koop, 1985; Shepard, 1978).

2.4. The Acknowledgement of a Spatial Factor

The first identification of spatial ability as a major factor in human intellect was a 1921 paper by Thorndike. He drew an important distinction among three broad classes of intellectual functioning, as opposed to Spearman's "singular view" of intelligence. He argued that standard intelligence tests measured only "abstract intelligence." While Thorndike included abstract intelligence in his own threefold model, he highlighted that "mechanical" and "social" intelligence were equally important. Thorndike's publication serves as the starting point for published spatial ability research. Through his work, he defined "mechanical intelligence" as the ability to visualize relationships among objects and understand how the physical world worked. Thorndike called for measures for these other types of intellect and set the stage for all the spatial ability research that would follow.

Afterward, Kelley (1928) and British contemporary El Koussy (1935) also challenged the verbal-based definition of intelligence (Burnett & Lane, 1980; Miller & Bertoline, 1991). El Koussy examined spatial intelligence and, consequently, was instrumental in developing methods for measuring it. El Koussy found evidence for the existence of a factor "K," which he defined as the ability to obtain and utilize visual spatial imagery. Kelley went further with his notions that the manipulation of spatial relations was another distinct factor within spatial ability.

Similarly, Thurstone (1938) studied primary mental abilities and defined a "space" factor that represented the ability to operate mentally on spatial or visual images. His theory was that intelligence was made up of several primary mental abilities rather than a single holistic factor. He was among the first to propose and demonstrate these factors through his Multiple Factors theory. The theory identified seven primary mental abilities, which included associative memory, number facility, perceptual speed, reasoning, spatial visualization, verbal comprehension, and word fluency. This theory was the basis for intelligence tests that yield a profile of individual performance from several ability scores, rather than the single mark.

2.4.1. Multiple Space Factors

Through subsequent research and using abstract nomenclature, Thurstone (1950) identified three primary spatial factors within spatial ability.

Literature that followed replaced Thurstone’s scientific designations with more descriptive terms (Smith, 1964). Mental rotation (S1) was defined as the ability to recognize an object if moved to different orientations or angles. Spatial visualization (S2) was the ability to recognize the parts of an object if they were moving or displaced from their original position. Spatial perception (S3) emerged as the ability to use one’s body orientation to relate to questions regarding spatial orientation.

Following Thurstone, many researchers attempted to name and define the factors that comprise spatial ability and there was little consistency or coordination between them. This disagreement in nomenclature and definition has been a limiting factor in spatial ability research. D’Oliveira (2004) acknowledges that conflicting perspectives are seen in (1) the definitions of spatial ability, (2) the number of abilities identified, (3) factor names, and (4) tests used to measure each factor.

To highlight these conflicts, Table 2.1 shows the naming and definition of these factors throughout the various seminal contributions. Typical tests for measuring these attributes are also listed. Table 2.1 is a composition of several charts throughout the literature, but primarily Hegarty and Waller (2005), Lohman (1984), and McGee (1979a).

Table 2.1.

Researchers, Factors, Definitions, and Markers

Researchers	Factors	Definitions	Markers
Thorndike, 1921	"mechanical" ability	The ability to visualize relationships among objects and understand how the physical world worked	Completion, Arithmetic, Vocabulary, and Directions test (CAVD)

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

McFarlane, 1925	"practical ability"	Adept at judging concrete spatial relations	Fitting Shapes, Pattern Perception, Completion, Analogies, Form Equations, Cube (non paper and pencil: Construction Test, Healy's Puzzle Box)
Kelley, 1928	Spatial factor	The mental manipulation of shapes	Speed in Reading, Power in Arithmetic; Memory for Meaningful Symbols, Memory for Meaningless Symbols; Manipulation of Geometric Forms
El Koussy, 1935	"K" factor	Ability to obtain and the facility to utilize, spatial imagery	Area Discrimination, Memory for Designs, Form Relations, Fitting Shapes, Form Equations A-C, Overlapping Shapes, Pattern Perception, Spatial Analogies, Classification, Band Completion, Correlate A & B, Mechanical Explanations, Mechanical Completion

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Thurstone, 1938	Space (S)	Facility in spatial or visual imagery	Flags, Lozenges A & B, Cubes, Block Counting, Pursuit, Hands, Figure Classification, Surface Development, Form Board, Syllogisms, Verbal Classification, Sound-grouping
Guildford & Lacy, 1947	Spatial Visualization	An ability to imagine the rotation of depicted objects, the folding or unfolding of flat patterns, the relative changes of position of objects in space, the motion of machinery.	Guilford-Zimmerman Spatial Visualization, Pattern Comprehension, Mechanical Movements, Mechanical Principles, Spatial Visualization, Directional Plotting
	Spatial Orientation	An ability to determine relationships between different spatially arranged stimuli and responses and the comprehension of the arrangement of elements within a visual stimulus pattern.	GZ Spatial Orientation, Stick and Rudder Orientation, Two-Hand Coordination Test, Directional Orientation, Discrimination Reaction Time, Dial and Table Reading, Aerial Orientation, Complex Coordination

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Thurstone, 1950	S_1	An ability to recognize identity of an object when it is seen from different angles, or an ability to visualize a rigid configuration when it is moved into different positions	Punched Holes, Form Board, Surface Development, Paper Puzzles
	S_2	An ability to visualize a configuration in which there is movement of displacement among the internal parts of the configuration	Cubes; Flags, Figures and Cards; Lozenges
	S_3	An ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem	Cubes; Flags, Figures and Cards; Lozenges

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

French, 1951	Visualization (V_i)	An ability to comprehend imaginary movements in three-dimensional space or the ability to manipulate objects in the imagination	Form Board, Punched Holes, Surface Development
	S (Space)	An ability to perceive spatial patterns accurately and to compare them with each other	Cards, Figures, and Flags; Cubes; Spatial Orientation of the Guilford-Zimmerman Aptitude Survey;
	Spatial Orientation (SO)	An ability to remain unconfused by the varying orientations in which a spatial pattern may be presented; dimensionally less important to the factor than the rotational position of presentations	

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Michael, Guilford, Fruchter, & Zimmerman, 1957	Visualization (V_z)	Mental manipulation of visual objects involving a specified sequence of movements	Paper Folding, Form Board, Punched Holes
	Spatial Relations and Orientation (SR-O)	Ability to comprehend the nature of the arrangement of elements within a visual stimulus pattern primarily with respect to the examinee's body as a frame of reference	Cube Comparisons Test, Guilford-Zimmerman Spatial Orientation, Card Rotations
	Kinesthetic Imagery (K)	Merely a left-right discrimination with respect to the location of the human body	Hands; Flags; Bolts

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Ekstrom, French, & Harman, 1976	VZ	An ability to manipulate or transform the image of spatial patterns into other arrangements, which requires that a figure be mentally restructured into components for manipulation, or the mental rotation of a spatial configuration in short-term memory and the performing of serial operations, perhaps involving analytic strategy	Form Board Test, Paper Folding Test, Surface Development Test
	S	An ability to perceive spatial patterns or to maintain orientation with respect to objects in space; requires that a figure be perceived as a whole	Card Rotations Test, Cube Comparisons Test

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

McGee, 1979b	Spatial Visualization	Ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object.	Paper Folding
	Spatial Orientation	Comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented	Cube Comparisons, Guildford-Zimmerman Spatial Orientation
Lohman, 1979a	Spatial Relations (SR)	Ability to solve such problems (typically mental rotations) quickly, by whatever means.	Cards, Flags, Figures
	Spatial Orientation (SO)	Ability to imagine how a stimulus array will appear from another perspective; there is often a left-right discrimination	None specified.
	Visualization (Vz)	Ability to solve complex spatial-figural content	Paper Folding, Form Board, WAIS Block Design, Hidden Figures, Copying

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Carroll, 1993	Spatial Visualization (VZ)	Ability in manipulating visual patterns, as indicated by level of difficulty and complexity in visual stimulus material that can be handled successful, without regard to the speed of task solution.	Paper Folding, Form Board, Cube Comparisons, Guilford-Zimmerman Spatial Orientation
	Spatial Relations (SR)	Speed in manipulating relatively simple visual patterns by whatever means (rotation, transformation, or otherwise).	Card Rotations
	Closure Speed (CS)	Speed in apprehending and identifying a visual pattern without knowing in advance what the pattern is, when the pattern is disguised or obscured in some way.	Snowy Pictures

Table 2.1 (continued).

Researchers, Factors, Definitions, and Markers

Carroll, 1993 (continued)	Flexibility of Closure (CF)	Speed in finding, apprehending, and identifying a visual pattern, knowing in advance what is to be apprehended, when the pattern is disguised or obscured in some way.	Hidden Pictures
	Perceptual Speed (P)	Speed in finding a known visual pattern, or in accurately comparing one or more patterns, in a visual field such that the patterns are not disguised or obscured.	Identical Pictures

Several of the researchers shown in Table 2.1 advocated the existence of only two spatial factors (visualization and spatial relations) with the latter category including both rotation (reorientation of an object) and orientation (reorientation of the viewer). In these studies, the researchers were typically not able to discern a difference between rotation and orientation. Recent studies have shown that it is likely that these earlier studies were not finding a difference between the two factors because instruments being used to reveal orientation could be solved by either orientation or rotation (Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001; Zacks, Mires, Tversky & Hazeltine, 2002).

2.4.2. Spatial Perception and Spatial Ability

While spatial perception contributes to overall spatial cognition, it is often considered separate and distinct from spatial ability (Linn & Petersen, 1986). This is much like the relationship between mental imagery and spatial ability—where researchers have investigated the impact of mental image vividness on spatial ability (Barry, 2002; Burton, 2003; Burton & Fogarty, 2002; Dean & Morris, 2003; Ernest, 1977; Galton, 1880, 1911; Kossyln, 1980; Marks, 1990; Mathewson, 1999; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Podell & Phillips, 1959; Poltrock & Agnoli, 1986; Walker & Marshall, 1982). Most of this research has indicated that tests of imagery are not highly correlated with spatial ability measures. Imagery does not limit spatial ability but success on spatial tasks often requires high-quality mental imagery, particularly on complex visualization tasks (Poltrock & Brown, 1984).

Similarly, spatial perception tests do not measure visualization, rotation, or orientation ability directly; instead, they measure the ability of an individual to ignore visually distracting information within the visual field (called field independency). Common tests include Piagetian tests such as the water-level test and the Rod-and-Frame test or the Embedded Figures Test, both developed by Witkin (1950). Although mental imagery use and field dependence/independence is not a specific factor in spatial ability, it is a related area of research that has some bearing on spatial ability—if not directly, than indirectly.

2.4.3. Modern Factor Research

Two additional threads of research have recently been pursued, proposing additional factors of importance in spatial ability. The first of these is a result of Carroll’s definition of spatial factors (1993). Carroll defined a hypothetical imagery factor that is "the ability in forming internal mental representations of visual patterns, and in using such representations in solving spatial problems" (p. 363). Burton and Fogarty (2002) set out to determine if this factor existed. In their research, they did find that imagery could be a reliable component when the testing of this ability is related to something other than normal, everyday imagery. Yet they also recommended further study and confirmation from other studies.

An additional emerging factor being examined is what Pellegrino and Hunt term "dynamic spatial ability" (1989, 1991). D'Oliveira (2004) stated that dynamic spatial ability is "the ability to deal with moving elements and relative motion" (p. 20). This factor was first examined by Hunt, Pellegrino, Frick, Farr & Alderton (1988). D'Oliveira's conclusion was that another way of looking at spatial ability is from a static versus dynamic quality. D'Oliveira acknowledged the general lack of valid tests and made a call for new dynamic ability measures. Several other researchers have conducted studies related to dynamic spatial ability as well (Anglin, Towers, & Moore, 1997; Contreras, Colom, Shih, Alava, & Santacreu 2001; Contreras, Colom, Hernandez, & Santacreu , 2003; Kyllonen & Chaiken, 2003; Law, Pellegrino, & Hunt, 1993; McCuistion, 1989; Pellegrino, Hunt, Abate, & Farr, 1987; Saccuzzo, Craig, Johnson, & Larson, 1996).

2.5. Developmental Research

The goal of developmental research in spatial ability is to answer questions related to when and how spatial ability develops. Seminal to this area is work by Piaget and Inhelder (1971), who conducted extensive studies with children and developed several spatial tests that are still used today. Developmental research predominately focuses on issues of age, but also delves into neurological issues such as hemispheric specialization.

2.5.1. Spatial Ability and Age

Piaget and Inhelder (1971) stated that spatial ability developed in three phases as the child matures. In the topological space stage, children acquire 2D skills and learn the relationship of objects to one another. During the projective space stage, children learn to work with 3D objects, particularly what objects look like from different vantages (orientation skills) and how objects look when they are rotated (rotation skills). In the third stage, individuals learn to go back and forth between 2D and 3D (the transition from projective space to Euclidean space). Here concepts such as parallelism, proportion, area, volume, and distance are acquired. Although lesser known, parallel work has been conducted by Bruner (1964) and Werner (1964).

Several studies have focused on developmental issues. Some studies focus on spatial ability differences at various age levels (Battista, 1990; Burnett, Lane, & Dratt, 1979; Fennema & Tartre, 1985; Lohman & Kyllonen, 1983; Salthouse, 1987; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Vandenberg, 1975). Others focus on the ages at which different aspects of spatial ability seem most apparent (Geiringer & Hyde, 1976; Linn & Petersen, 1986; Maccoby & Jacklin, 1974; Piaget & Inhelder, 1967, 1971; Salthouse & Mitchell, 1990; Smith & Schroeder, 1979; Tartre, 1990; Vandenberg & Kruse, 1978). Others focus on how spatial ability changes over time (Bishop, 1978; Brinkman, 1966; Clements, Battista, Sarama, & Swaminathan, 1997; Coleman & Gotch, 1998; Dodwell, 1963; Salthouse et al., 1990).

Research in this area has found that age affects spatial ability (Halpern, 2000). Spatial ability improves with age in childhood years (Flanery & Balling, 1979; Orde, 1996), but declines with age in adulthood (Lawton, 1994; Macnab & Johnstone, 1990; Pak, 2001). Age-related differences are often a result of differences in processing speed, knowledge, and experience (Salthouse, 1987) and age affecting accuracy in problem solving (Nunez, Corti, & Retschitzki, 1998). Spatial perception, that is, the ability to determine horizontal or vertical dimensions, does not emerge until around age nine (Olson, 1975) but spatial ability sex differences favoring males do exist at prepubertal ages (Linn & Petersen, 1986; Vederhus & Krekling, 1996), specifically at seven or eight years of age (Glasmer & Turner, 1995). These differences remain constant to age 18 (Johnson & Meade, 1987). However, sex difference emergence is highly dependent on the type of test (Voyer, Voyer, & Bryden, 1995); there is not a male advantage on all spatial factors. In addition, education can improve spatial ability with ages as young as nine (Rovet, 1983).

While not an exhaustive review of the literature in this area, these conclusions provide a sampling of representative studies. It should be noted that Piagetian tests (i.e., tests of conservation and water-level tests) are not considered direct measurements of spatial ability (visualization, orientation, rotations), even though the abilities they detect are related to spatial ability (Harris, 1978) as acknowledged earlier in this chapter.

2.5.2. Spatial Ability and Hemispheric Specialization

Hemispheric specialization is another area examined by developmental researchers. Here researchers strive to understand brain physiology and its relationship to spatial ability (Battista, 1990; Flanery & Balling, 1979; Harris, 1979; Hiscock, Iaraelian, Inch, Jacek, & Hiscock-Kalil, 1995; Lowery & Knirk, 1982-83; Rilea, Roskos-Ewolden, & Boles, 2004). There is general agreement that those with right-brain dominance perform better at spatial tasks and have more highly developed spatial abilities (McGee, 1976; McGlone, 1980; McGlone & Davidson, 1973). In addition, males are more often right-brain dominant and they mature more rapidly in this area (Harris, 1978). Thus, hemispheric specialization is examined from both the developmental and differential research lens. Hemispheric specialization is often a contributing factor when explaining sex differences, which is examined by differential researchers and is discussed in the next section.

2.6. Differential Research

Literature consistently notes the differences in the spatial performance of males versus females, frequently acknowledging male superiority. Maccoby and Jacklin (1974) spawned an incredible interest within this area when they discussed four areas in which sex differences emerge; the most notable is spatial ability. In addition to this, several researchers have provided reviews of the sex difference literature (Harris, 1978; Linn & Petersen, 1986; Lohman, 1979b; McGee, 1979b; Nyborg, 1983; Voyer, Voyer, & Bryden, 1995).

The differential literature is quite expansive—it appears to be one of the most contested issues in spatial ability research. Generally, in spatial tasks (particularly rotations), spatial perception, mathematical reasoning, and targeting ability, males outperform females. In verbal fluency, perceptual speed, memory, and certain motor skills, females outperform males (Kimura, 1996).

There are also a limited number of studies that indicate that the performance difference between the genders is decreasing, or in some cases, that it does not exist at all (Brownlow, 2001; Caplan, MacPherson, & Tobin, 1985, 1986; Fennema & Sherman, 1977; Hyde, 1981; Jagacinski & Lebold, 1981; Linn & Hyde, 1989; Lohman, 1994; Lord & Garrison, 1998; Michaelides, 2003; Smith & Litman, 1979).

One of the most controversial articles (Caplan et. al, 1985) criticized studies finding sex differences due to construct inconsistency (the definition of spatial ability) and small effect sizes of those studies. However, the response from the community was tremendous in refuting these claims (Burnett, 1986; Eliot, 1986; Halpern, 1986; Hiscock, 1986; Sanders, Cohen, & Soares, 1986). Responses acknowledged that while effect sizes in most studies are small, it does not trivialize the fact that there is a reliable gender difference.

2.6.1. Sex Differences in Spatial Perception

In spatial perception, studies of field orientation indicate that field independent learners have greater spatial ability (Gardner, Jackson, & Messick, 1960; Manfredo, 1987; Miller, 1992c; O’Brien, 1991; Podell & Phillips, 1959; Sherman, 1974; Study, 2001; Thurstone, 1944). Spatial perception tasks are usually easier for males (Linn & Petersen, 1985; Witkin, 1950) and females are more often field dependent (Sherman, 1974, Witkin, Moore, Goodenough, & Cox, 1977). In addition, cognitive style (field dependence/independence) is relatively stable and unchanging (Miller, 1992c; Witkin, et. al, 1977) and it is an important variable in learning (Dwyer & Moore, 1998).

2.6.2. Sex Differences in Spatial Ability

Sex differences in spatial ability also favor males and are nearly "universal across regions, classes, ethnic groups, ages, and virtually every other conceivable demographic variable" (Eals & Silverman, 1994, p. 95). Male superiority is most demonstrative in tasks of mental rotation, with lesser differences evident in orientation and no differences evident in visualization (Harris, 1978; Linn & Peterson, 1986; Stumpf, 1983). Most researchers also acknowledge that the sex difference does not reliably appear until after puberty and that, maturation has an effect on spatial development—late maturation is related to high spatial ability (Nyborg, 1983).

These studies usually also acknowledge the affect of hormones on spatial ability. Estrogen negatively affects spatial ability, whereas testosterone has a non-linear affect on spatial ability (Alderton, 1989; Harris, 1978; Imperato-McGinley, Pichardo, Gautir, Voyer, & Bryden, 1991; Kimura, 1996; McGee, 1979a; Moffat & Hampson, 1996; Nyborg, 1983). Some of these studies go so far as to state that hormones are the overarching reason for the emergence of sex differences, while others focus on the "real-time" effect of hormones.

2.6.3. Reasons for Sex Differences

Researchers hypothesize several reasons for sex differences. For example, Eliot and Fralley (1976) mentioned sex-linked recessive genes, child-rearing, educational environments, or culture that could underlie the differences. They also acknowledge that it could be a complex interaction between these as well. As such, most of the literature can be reduced to an argument for biological factors or environmental factors. The next two sections will briefly review some of the studies in the "nature" versus "nurture" debate.

2.6.3.1. Biological Explanations

Several researchers conclude that the sex differences in spatial ability are a result of biological factors (Bock & Vandenberg, 1968; McGee, 1979b, 1982). A variety of studies have shown that spatial ability does indeed have a heritable component (Vandenberg, 1975, 1969; Vandenberg, Stafford, & Brown, 1968; Wilson & Vandenberg, 1978) and many demonstrate that spatial ability is as much (or more) inheritable than verbal ability (McGee, 1979a).

Nevertheless, various biological explanations for sex differences favoring males include overarching hormonal impacts (Fruchter, 1954; Gardner, Jackson, & Messick, 1960; Newcombe, Bandura, & Taylor, 1983; Nyborg, 1983), a theory on an X-linked recessive gene (Bock & Kolakowski, 1973; Stafford, 1961; Vandenberg & Kruse 1979; Walker, Krasnoff, & Peaco, 1981, Yen, 1075), as well as an evolutionary theory related to male and female roles (Eals & Silverman, 1994; Silverman & Eals, 1992).

Of the posited biological theories, the X-linked recessive gene theory has been a primary focal point. However, one critical article (Boles, 1980) refutes this theory through reanalysis. Boles states that most of the studies showing evidence for this theory used sample sizes that were too small for confidence or yielded statistically insignificant results. Among the articles discussing X-linked recessive genes, this appears to be the only article calling the theory into question.

Regardless of the theoretical vantage, much effort has been put into examination of the biological basis for sex differences. The opposing view is that environment plays the primary role in individual development. The next section will provide an overview to the literature in this area.

2.6.3.2. Environmental Explanations

Like biologically based views, researchers have devoted much study to role of environment in the development of spatial ability. This viewpoint purports that cultural (Belz & Geary, 1984; Berry, 1971; Mann, Sasanuma, Sakuma, &

Masaki, 1990), social (Belz & Geary, 1984), sex-roles and stereotypes (Nash, 1975; Tracy, 1987, 1990), developmental (Tracy, 1990), and educational factors (Battista, 1981; Bishop, 1989; Conner, Serbin, & Schackman, 1977; Harris, 1978) are sources for differences in spatial ability.

Sherman (1967) specifically argued that gender differences in spatial ability exist due to varied experiences—his belief was that environmental differences play a primary role in the development of spatial ability. Several others agreed with this viewpoint (Baenninger & Newcombe, 1989; Beltz & Geary, 1984; Berry, 1971; Bishop, 1980; Harris, 1978).

While many of these environmental factors are straightforward, the educational factors that are purported to impact spatial ability development are many. Researchers believe that problem solving strategies and skills (Clements & Battista, 1992; Hill & Obenauf, 1979; Kyllonen, 1981; Kyllonen, Woltz & Lohman, 1981; Lohman, 1987; Mislevy, Wingersky, Irvine, & Dann, 1990); mathematical background, achievement, and problem solving ability (Aiken, 1971; Brendzel, 1981; Brown & Wheatley, 1989; Conner & Serbin, 1985; Fennema & Sherman, 1978; Friedman, 1995; Humphreys, Lubinski, & Yao, 1993; Landau, 1984; McKee, 1983; Michaelides, 2002; Moses, 1977; Pearson & Ferguson, 1989; Wheatley, Brown, & Solano, 1994); as well as musical background (Harris, 1978; Heitland, 2000a; Heitland, 2000b; Mason, 1986a; Robichaux & Guarino, 2000) are potential roots for the development of spatial ability, and therefore, the reason for sex differences.

2.6.3.3. Current Perspectives on Sex Difference Origins

While evidence for gender or environment (or an interaction of the two) is not conclusive, it is clear that they both play some role in the development of spatial ability and therefore, the differences that are exhibited (Harris, 1978). Several researchers advocate overcoming arguments that one or the other is the only agent, and instead, acknowledging that both biological and environmental factors contribute to the development of sex differences (Allen 1974; Brosnan, 1998; Casey, Nuttall, & Pezaris, 1999). As stated by Vandenberg, Stafford, and Brown (1968), "It is time for psychologists to cease ignoring either source of variation [biological or environmental] and proceed with full recognition that the two are highly interdependent (p. 153)."

2.7. Information Processing Research

One final area of research focus is in the area of information processing research. As noted by Kyllonen (1984), "Information processing research attempts to trace the flow of information through the human cognitive system from the time some stimulus is initially perceived to the time an over response is taken" (p 17-18). Its goal is to understand the processes involved in cognition, their order, and the speed at which they occur.

Thus, many of these researchers have examined the speed and efficiency in spatial processing and its impact on the development of spatial ability. Several studies found that speed and efficiency of performing mental transformations does explain a certain degree of variation of spatial skills (Carpenter & Just, 1986; Lohman, 1979b; Metzler, 1973; Mumaw & Pellegrino, 1984; Pelligrino & Alderton, 1984; Poltrock & Agnoli, 1986; Salthouse et. al, 1990; Shepard & Metzler, 1971; Shepard & Metzler, 1988). Studies in this area have also examined strategies in solving spatial problems (Cooper & Mumaw, 1985; Gages, 1994; Kyllonen, Lohman, & Woltz, 1984; Lohman & Kyllonen, 1983; Moody, 1998). They found that high spatial ability individuals have a wider range of strategies and are better at determining when to use a particular strategy. However, both high and low ability individuals switch strategies (Kovac, 1989; Kyllonen et. al, 1981). Such studies have also examined real-world scenarios, rather than test-based examinations (Cohen & Cohen, 1985; Gluck & Fitting, 2003; Juan-Espinosa, Abad, Colom, & Fernandez-Truchaud, 2000; Lawton, 1994; Montello, Lovelace, Golledge, & Self, 1999). The information processing perspective has also been used as a lens through which to view differential studies (Lohman, 1984).

2.8. Summary of Research Perspectives

Each of the research perspectives described in the prior sections has added significantly to the body of spatial ability literature. Psychometric studies have been instrumental in defining spatial ability and its factors. Developmental studies have provided knowledge about how and when spatial ability develops. Differential literature expounds the differences between genders and the information-processing literature has focused on strategies and processes.

In attempting to understand the spatial phenomenon, most of these studies aim at learning more about spatial ability so that we can better tap into and development it. Spatial ability affects many fields and disciplines and is a predictor for success in many areas of life. The following sections will describe the importance of spatial ability, methods for measuring it, and the myriad interventions that have been used to improve it.

2.9. The Importance of Spatial Ability

Literature that highlights the importance of spatial ability abounds. Researchers in fields ranging from art and education to science and engineering have focused on spatial ability (Alias, Black, & Gray, 2002; Battista & Clements, 1996; Battista, Wheatley, & Talsma, 1982; Ben-Haim, Lappan, & Houang, 1985; Bishop, 1980; Blade, 1949; Burnett & Lane, 1980; Fennema & Sherman, 1977; Guay & McDaniel, 1977; Harris, 1978; Jagacinski & Lebold, 1981; Karlins, Schuerhoff, & Kaplan, 1969; Maccoby & Jacklin, 1974; Martin, 1968; Presmeg, 1986). Research has also focused on the predictive capability of spatial ability on job success. For a summation of studies showing the use of spatial tests to predict job performance, see Smith (1964) and Ghiselli (1973).

Researchers indicate that without spatial ability, success within specific knowledge domains is extremely limited. These domains, while not an exhaustive list, include architecture, astronomy, biochemistry, biology, cartography, chemistry, engineering, geology, mathematics, music, and physics (Anderson, 1976; Ben-Haim, Lappan, Houang, 1989; Bishop, 1978; McGee, 1979b; Harris, 1981; Hassler, Birbaumer, & Feil, 1985; Kali & Orion, 1996; Newcombe, 1985; Pallrand & Seeber, 1984; Rhoades, 1981; Siemankowski & MacKnight, 1971; Smith, 1964; Spearitt, 1996; Travis & Lennon, 1997).

Most of these studies acknowledge the criticality of spatial ability for general academic success. For example, Ursyn (1997) highlighted that learning, problem solving, and memorization requires the ability to visualize scientific concepts. Ben-Haim et al. (1985) explained that spatial ability is important to the study of mathematics, science, art, and engineering. Because of statements like these, researchers have shown much interest in better understanding spatial ability. A logical conclusion is made by Colman & Gotch (1998) when they stated, "if spatial perceptual skills are important to success, further research more rigorously pursuing the relations between intervention and spatial ability would be very useful" (p. 209).

Contributions such as these often make a call for more spatial ability education, training, and interventions. McArthur and Wellner (1996) acknowledged that the spatial ability of students is poorer today than in the past, due to decreased focus on spatial ability training. Several researchers highlighted the need for more focus on spatial ability training (Bishop, 1978; Habraken, 1996; Khoo & Koh, 1998; Kyllonen, Lohman, & Woltz, 1984; Lord, 1985; McKeel, 1993; Weinstein, 1984).

2.10. Measuring Spatial Ability

The tests that have been devised to assess various aspects of spatial ability are numerous. Over the years, such tests have ranged from instruments designed for experimental uses only to standardized testing instruments of a commercial nature.

Eliot and Smith (1983) provided a seminal volume that classifies and documents most spatial ability tests. Another such classification scheme was developed by Wattanawaha (1977). However, Eliot and Smith systematically collected tests from both commercial and private sources in an attempt to create an overall classification. Their work, while out of print, still stands as the common reference for the classification of spatial tests.

After gathering the assessments and reviewing them, Eliot and Smith grouped the spatial tests into single-task and multiple-task categories. In their initial review of tests, they found many that could be traced back to earlier tests. In such cases they used the earliest or original version in their review and analysis.

Based upon a composite of characteristics noted in Kelley (1928) and Lohman (1979b), Eliot and Smith (1983) initially grouped the single-task tests into task categories. The single-task test categories were defined in the following way:

1. copying – subjects copy a figure superimposed upon a framework of dots or crosses upon a similar but empty framework. This category also includes maze tasks (p. 38).
2. embedded figure – subjects identify or draw a given simple figure which is embedded, concealed or hidden in a more complex figure (p. 70).
3. visual memory – subjects are shown a figure briefly and must draw or identify the figure from memory (p. 109).
4. form completion – subjects combine imaginatively the various parts of a figure to complete a whole figure (p. 147).
5. form rotation – subjects indicate which of several figures, when turned or rotated imaginatively, will be the same as a given figure (p. 197).
6. block counting – subjects estimate number of blocks, shape of blocks, intersection of block faces in a pile of blocks (p. 249).
7. block rotation – subjects indicate which block, when turned or rotated imaginatively, is the same as a given block or subject (p. 288).

8. paper folding – subjects are given drawings which illustrate successive foldings of a piece of paper. The final drawing has a mark or hole in a specified place. Subjects predict mark or hole patter of unfolded paper (p. 326).
9. surface development – subjects imagine how a pattern can be rolled or abstracted from a given figure (p. 341).
10. perspectives – subjects align imaginatively two or more objects or reference points in drawing or picture to make judgments about viewpoints which differ from their own (p. 370).

Eliot and Smith (1983) also include three multiple-task test categories (not shown in their classification, but included in their directory of spatial tests). These multiple-task categories included:

1. combination tasks – subjects must solve two or more tasks for each item; e.g., rotate a figure imaginatively and then mentally unfold it as a pattern (p. 390).
2. collage tasks – subjects respond to a variety of tasks in one test rather than to similar items by subtests (p. 419).
3. composite tasks – a battery of spatial subtests which may either be administered separately or scored together as a single summed score (p. 423).

Using three prior research factor characterizations (used in various factor analysis studies), they were able to further group the single-task categories. The multiple-task categories were not grouped further. The first single-task characterization, whether the group of tests required the perception and retention of mental forms or the mental manipulation of visual shapes, allowed them to separate the categories into a recognition and manipulation division, as shown in Figure 2.3.

Recognition Division	Manipulation Division
1 Copying	6 Block Counting
2 Embedded Figure	7 Block Rotation
3 Visual Memory	8 Paper Folding

Figure 2.3. Eliot and Smith's initial classification based upon Kelley's descriptions (Eliot & Smith, 1983).

The second characterization separated tests that required within-plane tasks, such as form completion test, from those requiring across-plane tasks, such as rotation test. Finally, the third characterization examined the mental transformations involved in the test and ordered the tests based upon increasing complexity. Eliot and Smith's final scheme is shown in Figure 2.4.

Recognition Division	Manipulation Division
1 Copying	6 Block Counting
2 Embedded Figure	7 Block Rotation
3 Visual Memory	8 Paper Folding
4 Form Completion	9 Surface Development
5 Form Rotation	10 Perspectives

Figure 2.4. Eliot and Smith's classification of single-task spatial tests (Eliot & Smith, 1983).

2.10.1. Classification Based on Information Processing

A second viewpoint related to classification of spatial tests is that of Zimowski and Wothke (1986) who examined the item-feature effects of spatial tests. Rather than using factor analysis, they used item-level analysis. Additionally, Zimowski and Wothke approached the classification of spatial tests from an information processing perspective. They argued that many of the spatial tests that had been designed and used did not require spatial ability in their solution. While all the tests required the processing of visuospatial stimuli, not all required spatial processing for the solution, that is, ability that was distinct from verbal and general reasoning skills. Thus they reviewed the available tests and devised a scheme to evaluate whether a test was a valid measure of spatial ability based on review of the spatial content of the items in the test. Tests that utilized spatial faculties were termed analog assessments, whereas those that utilized verbal or general reasoning were termed non-analog.

Zimowski and Wothke (1986) outlined the properties of item features shown to exhibit or require spatial ability for solution. These included:

1. Tasks involving judgments among rotated stimuli
2. Stimuli that differ by orientations other than 180 degrees
3. Distracters of the rotation tasks that are mirror images of the reference stimuli or structurally equivalent forms
4. Items requiring whole-whole rather than part-whole or part-part comparisons
5. Items requiring the rotation of an entire object as a rigid whole rather than the rotation of only one or several pieces of the object relative to the whole

Given these requirements, Zimowski and Wothke (1986) identified the following measures as valid measures of spatial ability, ones that resist non-spatial (non-analog) methods of solution:

1. *Vandenberg-Shepard Mental Rotations Test* (Vandenberg, 1971)
2. *The Guilford-Zimmerman Spatial Visualization Test* (Guilford & Zimmerman, 1947b)
3. *The Analog Subset of the Incomplete Open Cubes Test* (Zimowski, 1985)

Tests that were called non-analog (those that were susceptible to solution by non-spatial means) included:

1. *The Nonanalog Subset of the Incomplete Open Cubes Test* (Zimowski, 1985)
2. *The Space Relations Subtest of the Differential Aptitude Test Battery* (Bennett, Seashore, & Wesman, 1974)
3. *Embedded Figures* (Witkin, 1950)
4. *Raven's Progressive Matrices Test* (Raven, 1938)
5. *Minnesota Paper Form Board Test* (Likert & Quasha, 1970)
6. *Paper-Folding Test* (French, Ekstrom, & Price, 1963)

Zimoski's subsequent work continues to provide evidence that many of the generally accepted measures of spatial ability are not truly valid from a mental processing standpoint (Zimowski & Wothke, 1987, 1988).

2.10.2. Vandenberg's *Mental Rotations Test*

Of importance to this research is the Vandenberg *Mental Rotations Test* (sometimes also called the Vandenberg-Shepard *Mental Rotations Test* or MRT). Created by Stephen Vandenberg using block configurations originally created by Shepard and Metzler (1971), the paper-based MRT test has been used in various studies related to engineering graphics (McCuistion, 1990; Miller 1992c; Study, 2001; Zavotka, 1985) and is a valid and reliable test of spatial rotation ability.

In a 1978 article, Vandenberg and Kuse introduced this new spatial test and provided background on its construction as well as metrics related to it. In their contribution, they reported that with large samples (3,268 adults and adolescents of age 14 years or older), the test exhibited internal consistency (Kuder-Richardson 20 = .88) and test-retest reliability (.83). These metrics were also confirmed by documentation in the *Directory of Unpublished Experimental Measures* (Goldman & Osborne, 1985). This publication also reported that validity correlations of the MRT with other spatial tests range from .31 to .68. Vandenberg and Kuse (1978) also reported that the MRT has shown only correlations with tests of verbal ability. Subsequence reviews of the MRT by Zimowski and Wothke have reconfirmed the validity and usefulness of the MRT (1986).

The MRT test contains 20 test items in which the test taker examines a three-dimensional perspective pictorial of a configuration of rigidly connected blocks. The test taker must then choose which two of the four response items are the same object in a different orientation. The correct alternatives are always identical to the stimulus object but are shown in a rotated position. Figure 2.5 shows an example of two questions from this test.

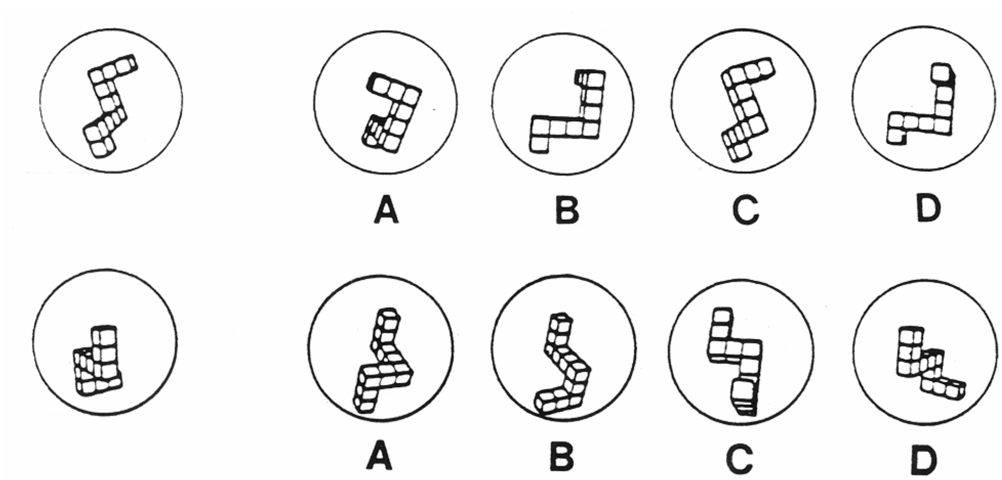

Figure 2.5. Two sample test items from the Vandenberg Mental Rotation Test (Vandenberg, 1971).

As originally reported by Vandenberg and Kuse (1978), university students, high school students, and elementary school students can complete the test within 10 minutes. The recommended procedure for scoring is to count each question as correct if both choices are correct and to give no credit otherwise.

Due to public domain access to the MRT test; its high validity, reliability and continuing support as a valid measure of spatial ability; and its use by prior researchers; this study used the Vandenberg MRT test as a method for determining the spatial ability of students (see Chapter 3).

2.11. Methods for Improving Spatial Ability

While there are a limited number of studies that question the effect of training on spatial ability (Levine, 1980; McFie, 1973; Smith, 1964; Witkin, 1969), the quantity of opposing literature is much greater (Bishop, 1978; Blade & Watson, 1955; Brinkmann, 1966; Burnett & Lane, 1980; Coleman & Gotch, 1998; Debono, 1976; Dixon, 1997; Eisenburg & McGinty, 1977; Ferrini-Mundy, 1987; Khoo & Koh, 1998; Kyllonen, Lohman, & Snow, 1984; Kyllonen, Lohman, & Woltz, 1984; Languis, 1998; Lord, 1985; Maxwell, Kinnear, Crooke, & Biddle, 1975; McKeel, 1993; Miller and Bertoline, 1991; Poole & Stanley, 1972; Rhoades, 1981; Rosenthal & Morrison, 1977; Rovet, 1983; Stinger, 1975). Based on the balance of literature and their results, it appears that many different types of interventions can indeed improve spatial ability.

Researchers have used numerous methods in an attempt to further spatial ability, each with varying levels of success. To study spatial ability, researchers have used traditional paper and pencil (Dejong, 1977; Newlin, 1979), real models (Miller, 1992a; Wiley, 1989, 1990), 2D CAD (Mack, 1994, 1995), 3D CAD (Braukmann & Pedras, 1993; Devon, Engle, Foster, Sathianathan, & Turner, 1994; Leach, 1992; Miller, 1992b; Shavalier, 2004; Vanderwall, 1981), 3D animation (McCuistion, 1989, 1990; Wiebe, 1993; Yang, Andre, & Greenbowe, 2003; Zavotka, 1987), interactivity (Gagnon, 1986), and computer games (Dorval

& Pepin, 1986; Pepin, Beaulieu, Matte, & LeRoux, 1985). The desktop computer provides an environment that allows for development and delivery of both static and dynamic media much more readily than in the past (Anglin, Towers, & Moore, 1997; Park, 1998; Wiebe, 1993). With the ever-increasing technological deluge available, notwithstanding the impact of the web, research in this era will likely continue for quite some time.

Several researchers have integrated direct instruction into classroom activities with positive results (Baldwin, 1985; Ben-Haim, 1983; Ben-Haim et al., 1985; Ben-Chaim, Lappan, & Houang, 1988; Clements et al., 1997; Conner et al., 1977; Friedlander, 1985; Smith & Litman, 1979; Smith & Schroeder, 1979; Tillotson, 1984). Typically, such instruction teaches students visualization principles ("picturing objects in the mind") and then mental manipulation of those objects (rotating, moving, and deconstructing). Often such materials are context-specific. In chemistry, activities relate to the bonding of atoms or other such concepts. In engineering, students picture orthogonal views of three-dimensional objects. Moreover, in mathematics, students mentally picture and manipulate a host of algorithms, numerical patterns, or relationships. In each of these cases, spatial ability is directly involved.

Aside from varied content areas, the literature related to direct spatial ability instruction also spans all age levels. Clements et al. (1997) examined the effect in elementary students. Results indicated that instruction had a strong positive effect on student spatial ability. Student scores improved with respect to accuracy and number of test items completed. Smith and Schroeder (1979) examined fourth graders and found that both boys and girls responded; both groups improved their spatial visualization ability following instruction.

Researchers conducted similar studies with middle school students (Ben-Haim, 1983; Ben-Haim et al., 1985; Ben-Chaim et al., 1988). Results indicated that males and females at all grade levels benefited considerably from participation in activities involving spatial visualization tasks. They also tested the long-term effect. After a period of a year, the effects of the training were still present. Results from a study conducted by Baldwin (1985) corroborate these results.

While there are studies that show no effects (Baenninger & Newcombe, 1989; Blatter, 1983; Conner et al., 1977; ChanLin, 2000), most literature in this arena shows a positive effect of direct instruction in spatial ability improvement. As indicated by Tillotson (1984) and exemplified in the other studies referenced here, spatial visualization ability is a trainable attribute.

2.12. The Future of Spatial Ability Research

Given the history of spatial ability research, as well as the current "era," it is likely that spatial ability research will continue along two concurrent themes. One is a return to where spatial research started, that is, the role it plays in the measurement of intelligence. The second is continued study of the impact of computing technology on further defining and improving spatial ability.

2.12.1. Refocusing On Intelligence

Concerning the first of these paths, Gardner (1984, 1993) built upon the framework provided by past studies of general intellectual capabilities to provide further classification of spatial and other abilities. Gardner proposed a multifaceted model of intelligence in which spatial abilities are one of seven major components. His model of intelligence implies that there are many aspects that contribute to the construct of "IQ"; ones that tests of intelligence often do not measure either due to a lack of acknowledgement or due to the impracticality of measurement.

Gardner’s *Theory of Multiple Intelligences* includes a definition of linguistic, musical, logical-mathematical, spatial, bodily-kinesthetic, interpersonal and intrapersonal abilities; all which contribute to the intelligence within the individual. More recently, Gardner has proposed two more capacities: naturalistic and existential intelligence. However, the defense of these later components as distinct intellectual competencies is still not concrete. For each of the original seven areas, Gardner presents comprehensive discussion as to the validity of each area based upon both cognitive and biological research.

Of relevance is Gardner's discussion of spatial ability. He defines spatial intelligence as the ability to think in pictures and images, the ability to perceive, transform, and recreate different aspects of the visual-spatial world. His definition also includes sensitivity to visual details and the ability to draw or sketch those ideas graphically.

Concerning the visual-spatial faculty, Gardner describes multiple means of measurement. One can use not only familiar paper and pencil tests such as *Guilford-Zimmerman Spatial Visualization Test* or Vandenberg's *Mental Rotations Test*, but also verbal exercises describing events or tasks. Being able to visualize verbal descriptions and instructions utilizes the same cognitive facilities as those examined by graphically based visualization tests.

Yet, Gardner's most significant contribution is that spatial ability stands as an important and key component of intelligence, equivalent to linguistic and logical-mathematical ability. Gardner's explanation continues by stating that the intelligences are discontinuous, but also interrelated and adjoined. For example, while it can be disjoined, as studies with exceptional students indicate, spatial intelligence also works in juxtaposition with logical-mathematical ability, that is mathematical ability and the ability to reason. Thus, there are both dependent and independent aspects of the intelligences.

Nonetheless, the primary emphasis of Gardner's work is that to define intelligence more accurately, researchers need more expansive testing and measurement. As Gardner notes, current tests generally focus on linguistic and mathematical abilities, with less focus on measuring other constituents. However, these other intelligences, including spatial ability, are as vital to accurately determining intelligence as the two primary foci that subsume most IQ tests. It is likely that research in this area, while not specifically focused on spatial ability, will continue and will assist spatial ability researchers indirectly.

2.12.2. Utilizing Technology

Many of today's computer-based tools are well suited for visualization instruction, remediation, and inquiry. The desktop computer provides an environment that allows for development and delivery of both static and dynamic media much more readily than in the past (Anglin et al., 1997; Park, 1998; Wiebe, 1993), not to mention real-time media. The computer can easily become an extension of the mind, allowing students to view their cognitive processes. Frequently, the computer monitor becomes both a looking glass and a tutor for mental processes that are often difficult to identify and analyze using traditional methods.

Yet, the complexity of some environments and the overload of the human senses can add to the cognitive workload required of a student and consequently become a barrier to the honing of visualization skills, or for that matter, any cognitive ability (Metallinos, 1994). In any computer-based environment, the mental focus should not be upon the digital tool or how to access the information. Rather, exercising visual abilities or the skills one wishes the student to acquire is the emphasis.

Frequently, digital tools can become a hindrance to learning, particularly upon first exposure. As it relates to environments for visualization, suitably designed digital tools must provide affordances and conceptual clues that allow the student some relationship or correlation to the real world so that they may easily operate within the environment (Gibson, 1986). When a computer is used, students must understand the environment and the methods for controlling it.

Several of the methods employed for visual ability improvement have led to further discoveries of mental capacities that comprise cognitive spatial abilities, as well as ways in which the student can improve those abilities. As technology has improved, students have become more readily able to externalize and exercise cognition with technology. However, there is a delicate balance between enabling and disabling learning with technology. As long as the computer, its interface, and controls do not interfere with the objectives for learning, the implementation of technology for spatial advancement is advantageous (Mohler, 1997).

The implementation of any learning strategy must also consider learning styles. While one method may be appropriate for some learners, that same method may be completely inadequate for others. Large proportions of learners may fall into a category that excels with a particular style of instruction. Therefore, strategies must coincide, or at least accommodate, various styles of learning. Technology indeed more readily permits this adaptation to the learner.

For example, Miller (1992b) noted the significant differences between visual and haptic learners, namely, how the use of computer-generated models can assist learners who fall in either category of learning. Miller noted that he suspected that the results were affected by other variables. However, he still recommended the use of advanced technologies, if for nothing more than the motivational and interest aspects that it induces. A significant variable that contributes to learning is motivation. Advanced technologies can increase student motivation toward learning conceptual and applied information (Bertoline, Miller, & Mohler, 1995).

Although many of the technologies employed in these recent studies do not indicate a greater degree of spatial ability attainment due to the digital treatment, they do point to technologies that can equivalently match results of prior methods of instruction. As described in many of the studies, most computer methods are as effective as traditional instructional methods and exercises (Bertoline, 1991; Braukmann & Pedras, 1993; Clements et al., 1997; Devon et al., 1997; Geban, Askar, & Ozan, 1992; Mackenzie & Jansen, 1998; McCuistion, 1990; Monoghan & Clement, 1999; Thomas, 1996; Trethewey & Belland, 1990; Yang & Greenbowe, 2003; Zavotka, 1987).

One of the most promising of these new technologies is virtual reality (VR). One of the detriments of other computer-based strategies is that the student is distant from the environment or objects, particularly as it relates to static images or animations. The advantage of VR technology is that it allows people to expand their perception of the real world in ways that were previously impossible (McLellan, 1998). McLellan described VR as a cognitive tool that allows dynamic and immediate interaction as well as immersion. Extending and enhancing human cognitive abilities is the aim of the interactivity inherent to VR. Thus, it provides a superb vehicle for enhancing and possibly improving spatial abilities.

Ross and Aukstakalnis (1993) proposed several scenarios for increasing visual abilities using VR technologies, specifically increasing a student's ability of visualization and spatial orientation. Note that spatial orientation includes not only the static relationship, but also the dynamic relationship between the user and the environment. Rotation and translation as well as the controls for performing these actions on the viewer and object(s) are included within this aspect of spatial ability. As suggested, VR appears to provide a better vehicle for testing, enhancing, and possibly improving both visualization and orientation skills. However, qualifying and quantifying the impact of its use needs more research.

VR is only one example of harnessing technology for spatial ability research. Many new technologies will likely find a place within the literature over the coming years. Some of these might include augmented reality (combination of VR with physical devices), pervasive computing, holography, collaborative environments, haptics, and wearable devices. It is highly likely that spatial ability research will continue with greater and greater involvement of computing devices of all shapes, kinds, and sizes.

2.13. Summary

This chapter has provided an overview to the literature related to spatial ability. It has summarized the various eras of research, the importance of spatial ability, methods for measurement, methods for improvement, and current trends and foci of the research.

The results of this review of literature provided confirmation of the importance and relevance of the questions posed in this study. None of the literature seems to attempt to answer the research question posed, that is, "What the spatial ability phenomenon is like from the student’s perspective?" While there are a few qualitative studies in this area, none has tackled the questions posed by this researcher directly. Moreover, the naturalistic approach is far from common.

With such a broad foundational canvas of discourse on spatial ability, and with an increasing acceptance of qualitative modes of inquiry by new disciplines, this study presents a timely approach in an attempt to answer an engaging question. Thus, the next chapter provides necessary background on qualitative inquiry as well as the specific methodological and framework details used in this research study.

CHAPTER 3. FRAMEWORK AND METHODOLOGY

The purpose of this research was to describe and analyze the background, experiences, and perspectives of individuals with varying levels of spatial ability, as outlined in Chapter 1. Due to the nature of the questions posed, the qualitative research tradition provided the best mechanism conducting this study. Because the quantitative approach dominates spatial ability research, this study provides a distinctive viewpoint to the existing body of literature.

This chapter outlines the methods that were used in this study, including study site, access, sampling, data collection, and analysis procedures. The chapter concludes with a discussion of trustworthiness and triangulation of data sources relative to this project.

3.1. Theoretical Framework

Two lines of thought need to be acknowledged relative to the theoretical framework for this study. First, the framework for this study could be described from the vantage of the research approach I chose, that is, the qualitative, phenomenological approach. Second, the framework could be specified from the vantage of my theoretical view of spatial ability and its development within the individual. In an attempt to satisfy the needs of the reader looking for one or the other of these framework discussions, the following two sections will address the theoretical framework from both perspectives.

3.1.1. Approach to Research

Acknowledgement of framework should likely define the five fundamental philosophical assumptions, that is, ontological, epistemological, axiological, rhetorical, and methodological assumptions. The latter of these will be omitted in this section; being that the remainder of the chapter is entirely devoted to a methodological discussion.

The ontology of this study is oriented toward the belief that reality is subjective and can be defined in myriad ways. Reality is whatever is seen, perceived, and understood by each individual. Foundational to phenomenology is the understanding that, although each individual perceives and experiences the world in a different way, there are common essences to that experience. There is also uniqueness due the subjective nature of reality in individual consciousness. Therefore, in phenomenology it is individual's experience, perception of experience, and the impact of these on the constructed reality of the individual that are of import.

From the epistemological vantage point, that is, the relationship between the researcher and that being researched, the phenomenological approach, like many qualitative traditions, requires direct engagement with the participant. Rather than creating distance to objectify the results, it is the closeness to the subject of study that provides value, rich description, and an in-depth expository on the phenomenon under study. It is due to this closeness that phenomenology provides a unique viewpoint.

Phenomenological research acknowledges that all research is biased and value laden. Rather than try to avert or eliminate bias and values, phenomenological studies instead embrace and openly acknowledge them. This is the axiological orientation of phenomenology. An important part of phenomenological reports are the sections that disclose the role of the researcher, his or her views on the topic of study, as well as the narratives that are analyzed concurrently with participant data. Through bracketing exercises, phenomenology requires that the researcher document and then, as much as is humanly possible, set aside his or her prior knowledge and viewpoints. In this way biases, values, and other researcher perspectives are openly available to the reader, allowing the reader to understand the potential impact of these "researcher lenses" on the findings and conclusions of the study.

As for the rhetorical, phenomenological studies are typically literary and use an informal style. Often written in first person, such studies employ the language of qualitative research with many first-person references and direct participant narratives as garnered though the various data sources.

Given the philosophical assumptions or perspectives that are the framework for the phenomenological approach, the next section provides a framework of my views on spatial ability and its development. Much of this expository is the result of the first epoché session that occurred prior to data collection (see section 3.6.5 for a description of these).

3.1.2. Approach to Spatial Ability

My perception of spatial ability is that it is composed of a variety of facets and that there are likely numerous things that contribute to it. Based on my own experiences, I agree with research that points to more than just innate influences. While indeed there could be some genetic, biological, or hormonal factors, I firmly believe that experiences and environmental factors probably contribute the most to the development of capability in this arena. Experiences with toys, music, hobbies, and so on seem to have a dramatic affect, not just on imagination, but also on the application of imagination toward spatial ability. In my own life, I believe that these types of experiential things prepared me to be so easily able to utilize my spatial abilities. I also perceive that the recent literature acknowledging the decrease in the gender gap in spatial ability is related in some way to the change in experiences that children have growing up today.

As it relates to the measurement of spatial abilities, I do agree that we have many valid and reliable tests of spatial ability available (and just as many that are not). Research by Zimowski (1986) provided an adequate list of spatial tests that access the various spatial components. However, there is still much concerning spatial visualization we do not understand. Based on the most recent research, we can see that spatial ability is composed of several attributes: spatial visualization, spatial rotation, and spatial orientation. Yet, we still do not fully understand how these factors work or what specifically causes them to develop.

Like many researchers, I believe that spatial ability is an attribute that can be improved through specific activities. As well, research shows that the development of spatial ability—like many abilities—is more malleable or improvable at younger ages. Given my involvement at the university-level, my primary focus is determining the things I can do to help my students better visualize. Also of question to me, is why students so often have difficulty with spatial tasks.

Even with the breadth of literature on spatial ability, it seems odd to me that more focus is not attuned to developing this ability in the elementary and secondary schools. There is no end to the literature acknowledging the importance of spatial ability for success in the range of occupations that are available. However, there is still minimal focus on spatial ability in K-12 education. This, to me, is a significant problem.

In summary, my view of spatial ability is that it is an important cognitive ability; it is composed of at least three major factors (and several minor factors) for which there are a variety of valid assessment instruments. I believe spatial ability is something that can be developed with appropriate practice, but that this skill is more easily improved at younger ages. The differences in spatial ability that we see in students, while partially linked to biological or other factors, are attributable mostly due to experience and environment.

3.2. Methodology

Each of the questions addressed in this research was intended to reveal the phenomenon of spatial ability and its structure through the lived experience of the participants. What was the essence of each individual’s experience with the spatial ability phenomenon? What were the common essences of that experience amongst the various participants and what were the differences? To begin answering these questions, the similarities and differences in lived experiences between those classified as high and low in spatial ability were focused upon. To the extent that the study delves into the lived experience of the participant (describing what it is like for them), is the extent to which the study is inclined toward the phenomenological approach (Patton, 2002).

3.3. Study Environment

The following two sections provide relevant details concerning the study site and the course from which the participants were selected.

3.3.1. Study Site

This research was conducted at Purdue University, a land-grant university situated within West Lafayette, Indiana, which was one of the 25 largest universities in the U.S. at the time of the study. This Research Intensive University offered approximately 5,700 courses in more than 200 specializations, organized through 12 undergraduate colleges or schools and a Graduate School. Approximately 38,500 students were enrolled at the West Lafayette campus (34,000 are full-time students); while 30,000 others pursued coursework at four regional campuses and 10 Statewide Technology locations.

Historically, the primary academic emphasis at Purdue University was agriculture, engineering, science, and technology. However, the four largest schools within the university (by student count) were engineering, liberal arts, technology, and science respectively at the time of this study. Approximately 10 percent of the undergraduate population was composed of ethic or racial minorities and approximately 42 percent were women. The University conferred over 5000 Baccalaureate degrees, 1000 Master’s degrees, and 400 Doctoral degrees each year.

Purdue University had a rich history in engineering—being one of the primary aspects of its land-grant mission. Over the past 100 years, the various engineering programs at Purdue University have become nationally recognized programs. Several other schools and programs are also recognized nationally and internationally.

The research described in this report was conducted at the West Lafayette campus due to convenience. I was an employee of Purdue University and was located in the Department of Computer Graphics Technology in which the research occurred. One of the critical aspects of qualitative research credibility is access and emersion in the environment of the participants (Denzin & Lincoln, 2000). Conducting this study at my place of employment helped in meeting this criterion.

3.3.2. Participant Population

The sample for this study was selected from students in the Computer Graphics Technology course *CGT 163: Introduction to Graphics for Manufacturing* during the spring semester of 2006. At the time of this study, CGT 163 was a two credit hour course and students attended a one-hour lecture on Monday and Wednesday and a two-hour laboratory meeting each week. Due to the size of the course, there were two sets of lectures (called lecture divisions) taught by two different instructors, and students attended one of the two lecture divisions each week. Each lecture division had approximately 120 students. There were 14 lab sections taught by five different instructors. Each laboratory section had a maximum of 20 students.

CGT 163 was predominantly populated with freshman engineering students. It was a course taken by all Purdue mechanical and aeronautical engineering students, and it focused on freehand sketching and computer-aided design (CAD) to convey engineering ideas. The course also included a number of students from other disciplines as well.

Many studies have indicated the importance of spatial ability to the success of engineering students (for a review see Miller, 1996). CGT 163 was selected because the development of spatial ability was one of its primary goals. CGT 163 students had to be able to transform two-dimensional representations of objects into constructed three-dimensional objects fluidly, and vice versa. Spatial ability was a critical cognitive factor for successful use of computer-based, three-dimensional modeling design tool also (CATIA was the software used). Due to the importance of spatial ability for success in this class, it seemed an appropriate population from which to draw purposeful samples for this study.

3.4. Permissions

The next three sections outline the permissions that were sought as part of this study. Permissions included course instructor permission for access and execution of the study in his class, permission for use and modification of the Vandenberg *Mental Rotations Test* (MRT), and Human Subjects approval to conduct this study at Purdue University.

3.4.1. Course Instructor and Access

The instructor for CGT 163 gave me permission to observe the students, solicit specific participants for the study, and to include certain aspects of this research project as assignments in the course. Three of the CGT 163 assignments were modified for the purpose of this study. Two assignments required the students to take the MRT, and one assignment was a background questionnaire. Appendix A shows the MRT test that was administered at the beginning and the end of the course, Appendix B shows the Scantron scoring sheet used with the MRT on both occasions, and Appendix C shows the background questionnaire.

The course instructor decided that extra credit would be given to students participating in this study. Students who were invited to participate would receive

50 assignment points. In accordance with Human Subjects Guidelines, students not participating in the study were given the option of constructing a three-dimensional model for the same number of extra credit points (see Appendix D).

3.4.2. MRT Use and Modification

Because tests are protected by copyright law, I sought permission to use the MRT test and to modify its instructions. I contacted the University of Colorado, Boulder to gain the appropriate permissions (see Eliot & Smith, 1983). The response provided by officials from that institution indicated that the test author was deceased and that the test was now considered in the public domain by the university and the author’s estate, permitting use and modification of the test for this study without written permission, license, or release.

3.4.3. Human Subjects Approval

During the fall 2005 semester, I sought Human Subjects approval at Purdue University. After one round of revisions, permission was granted to conduct the study in CGT 163 during the spring 2006 semester. Of import was that I was not involved in an instructional capacity for the course in which the study was to take place, participants were not receiving monetary compensation for their involvement, and participation in the study did not involve risk to the participants beyond that faced in daily living. Appendix E provides the Research Consent Form approved by the Purdue University Human Subjects Committee for this study.

3.5. Unit of Analysis

One of the critical aspects in designing a qualitative study is determining the unit of analysis. The key issue in selecting and making decisions about the unit of analysis is to "decide what you want to be able to say something about at the end of the study" (Patton, 2002, p. 229). The primary question posed in this research was, "What is the spatial ability phenomenon like for students?" Thus, the individual student was the unit of analysis.

The second decision concerned the approach to sampling. Patton (2002) acknowledges that one of the defining marks of qualitative studies is the use of purposeful sampling—selecting specific participants that are exemplars in some way—as opposed to random sampling techniques. Of the 16 types of qualitative sampling strategies he mentions, the type selected for this study was extreme or deviant case sampling. Extreme or deviant case sampling was used because it seemed to provide the best opportunity to find information-rich cases relative to the spatial ability phenomenon. Patton (2002) defines this type of sampling as:

> ...learning from unusual manifestations of the phenomenon of interest, for example, outstanding successes/notable failures; top of the class/dropouts; exotic events; crises (p. 243).

For this study, students who exhibited high spatial ability and low spatial ability were the extremes selected.

The third decision was relative to the number of students needed to be able to describe the spatial ability phenomenon adequately. While acknowledging that single cases are often used in qualitative studies, Morse (1994) suggests that at least six participants be used in studies where one is trying to understand the essence of an experience. Creswell (1998) and Riemen (1986) recommend 10 and Dukes (1984) recommends studying 3 to 10 subjects.

Given these viewpoints, I selected 12 students to participate in in-depth interviews; and 12 students to participate in one of two focus groups, totaling 24 participants in all. Note that choice of data collection techniques is discussed in section 3.6 (e.g., Why were interviews and focus groups used?). Each set of 12 students was composed of six high ability students and six low ability students.

The groups of students and the activities they participated in are shown in Table 3.1.

Table 3.1.
Activities of the Participants

Students	Group	Ability	Activity
1-6	A	High	3 in-depth, individual interviews
7-12	B	Low	3 in-depth, individual interviews
13-18	C	High	1 focus group
19-24	D	Low	1 focus group

The following sections detail how students were identified according to spatial ability and then how they were selected for participation in this study.

3.5.1. Determination of Spatial Ability

To determine the two general groups (high and low spatial ability) from which the 24 participants were selected, a paper version of Vandenberg's *Mental Rotations Test* (MRT) was administered to determine student spatial ability. Although there are various measures of spatial ability, experts in the field of spatial visualization state that not all spatial tests are valid measures of spatial ability. Validity is simply whether a test truly measures what it purports to measure. Zimowki (1986) has shown that the MRT is a valid measure of spatial ability through correlations with other measures.

Reliability is the extent to which a test is repeatable and yields consistent scores. Concerning reliability, Vandenberg and Kuse (1978) reported their use of the MRT test yielded an internal consistency metric of .88 and a test-retest reliability metric of .83.

Another consideration was that many researchers have used the MRT. Zavotka (1985) and Miller (1992a) used the MRT to classify students according to spatial ability, as have many others. Studies in engineering often use the MRT because it measures the mental rotations construct, an important skill in the creation of orthographic views from isometric pictorials, and vice versa.

Another advantage was that the MRT was not a copyrighted test, making it readily accessible and modifiable. Due to all of these factors, it seemed acceptable and appropriate to use the MRT as the measure of spatial ability to determine high and low visualization ability students in this study.

3.5.2. Use of the MRT

The MRT was administered during the first week of the course during the spring 2006 semester. The test instructions were modified so that it could be scored using a Scantron scoring sheet. Both the MRT (with modified instructions) and the Scantron scoring sheet are provided in Appendix A and B respectively. While a redrawn version of the MRT exists (see Peters, Laeng, Latham, Jackson, Zaiyouna, & Richardson, 1995) and a computer-based version exists (Strong & Smith, 2002), I used a version created by Miller (1992c). I scanned it into the computer and cleaned up some of the images for clarity purposes.

In their original 1978 article, Vandenberg and Kuse stated that students at all grade levels could complete the exam in about 10 minutes. However, this was based upon allowing the students to write directly on the exam booklet (students would select two correct responses for each test item, as described in Chapter 2). With nearly 240 students enrolled in CGT 163, I decided to modify the exam so that it could be scored with a Scantron system, rather than having to score 240 exams manually. This was also done by Miller (1992c).

Due to technical limitations of the Scantron system, namely the system’s inability to score "and" type correct responses (e.g., A and B as a correct response), students had to determine which two answers were correct on each item in the test booklet and then select from the following responses to accommodate the Scantron sheet:

(1) A & B

(2) A & C

(3) A & D

(4) B & C

(5) B & D

(6) C & D

Because the students in this study had to transpose their answers from the MRT exam booklet to the Scantron scoring sheet, the time limit of the exam was increased to 10 minutes per section, rather than 5 minutes per section. The determination of 10 minutes was based upon the my approximation of the additional time it would take to transfer answers from the exam booklet to the Scantron.

3.5.3. Recruitment and Selection of Participants

During the first week of the course in both lecture divisions, the course instructor permitted me to make a call for students who would like to participate in the research study. After a brief 10-minute overview, students signed a sheet or emailed me to express their interest in participating. One hundred and thirty-three students expressed an initial interest in participating.

During the first week of the course, the MRT was taken by all students as a laboratory assignment. Students also filled out a brief questionnaire as a laboratory assignment. Once the MRT was scored, I corroborated the scores with student information provided by the course instructor. The student information included student name, major, number of semesters in the major, and gender. I then combined the student information and MRT scores with the names of those who had volunteered to participate, resulting in a final list of potential participants. Background questionnaires and MRT scores for students who had not volunteered were discarded.

With the final list of potential participants, I then looked at the MRT scores in an attempt to separate the students who had volunteered into high and low ability groups. Originally, I was going to use an approach similar to Zavotka (1985), where a score of 14 or higher on the MRT was used to identify high spatial ability and a score of eight or less was used to indicate low spatial ability. However, students scored better than expected on the MRT exam. One plausible reason was that the students were technology-intensive majors. One would expect that technically oriented students would score higher than a general population of college students. Another logical reason could have been the additional time provided on the MRT test.

Even though students scored better than expected, the MRT still provided a measure that could be used to determine high ability students from low ability students within the group of volunteer participants. Rather than using specific scores as delimiters, I instead chose 12 of the highest scores and 12 of the lowest scores for participation in the study. The high spatial ability group included scores that were higher than 18 and the low spatial ability group included scores ranging from five to 15.

While the primary criterion for participation in this study was spatial ability as measured by the MRT, I also wanted to include gender as a consideration, such that each group of 12 students contained at least six females. This was more challenging than originally expected. However, as shown in Table 3.2, all groups except one had one-half females.

In addition to considering gender, I also took into account major and number of semesters in the major when determining which students would participate. In assigning students to groups, the order of matching precedence was MRT score, gender, major, and then semester. Table 3.3 shows the composition of the groups and my best attempt at matching within-group students across gender and the other characteristics.

Table 3.2.

Gender Composition Within Groups

Group	Number of Males	Number of Females
A	3	3
B	3	3
C	4	2
D	3	3

Table 3.3.

Group Composition and Within-Group Matching

Interview and Focus Group						Focus Group Only					
Group A						Group B					
#	Match[1]	MRT	Sex	Maj[2]	Sem[3]	#	Match	MRT	Sex	Maj	Sem
1	A1	19	F	AAE	4	7	B1	7	F	LA	3
2	A1	19	M	ME	4	8	B1	5	M	ME	4
3	A2	19	M	E	2	9	B2	11	F	E	2
4	A2	19	F	E	2	10	B2	11	M	AT	2
5	A3	18	F	E	2	11	B3	14	M	E	2
6	A3	18	M	E	2	12	B3	14	F	ME	2
Group C						Group D					
#	Match	MRT	Sex	Maj	Sem	#	Match	MRT	Sex	Maj	Sem
13	C1	19	F	E	2	19	D1	10	M	E	1
14	C1	19	M	ME	3	20	D1	8	F	LA	2
15	C2	19	F	E	2	21	D2	12	F	E	4
16	C2	19	M	E	2	22	D2	12	M	E	2
17	C3	18	M	E	2	23	D3	15	M	E	2
18	C3	18	M	E	2	24	D3	15	F	E	2

[1] Match column shows students who shared similar characteristics (students who were matched).
[2] Maj column represents university Major, which included Aeronautics and Astronautics (AAE), Aviation Technology (AT), Freshman Engineering (E), Liberal Arts (LA), and Mechanical Engineering (ME).
[3] Sem column represents number of semesters in the major.

Once the participants had been assigned to groups, I sent out emails to participants, inviting them to participate (see Appendix F for examples). As soon as volunteers responded and acknowledged their continuing interest, I began scheduling the in-depth interviews and focus group meetings. The 90-minute interviews were designed to take place over the spring semester in my office in Knoy Hall of Technology, room 347. It was believed that this room would provide a comfortable and safe environment for the interviewees; indirectly assisting in the quality of interviewee response. The 1-hour focus groups were to take place at the end of the semester in a scheduled meeting room. A meeting room was chosen for the focus group meetings so that a white board or chalkboard could be used for group questioning and discussion.

The first set of in-depth interviews occurred within the fifth and sixth weeks of the semester. The second set of interviews occurred within the seventh, eighth, and ninth weeks of the semester. The third round of interviews occurred within the tenth, eleventh, and twelfth weeks of the semester. Finally, the focus group meetings occurred during the fourteenth and fifteenth weeks of the semester. The goal was to have the first and second interviews completed prior to the course sketch exam, and to have the focus groups meet after all interviews.

3.6. Data Collection

Creswell (1998), Moustakas (1994), Seidman (1998), and Van Manen (1990) acknowledge that the primary data collection technique used by the phenomenologist is the long interview. They also acknowledge that self-reflection (Husserl’s epoché) is critical throughout the process. Regardless of form—structured, semi-structured, or unstructured—interviews for phenomenological data collection are typically one and one-half to two hours long (Creswell, 1998).

In addition to this primary method, data can also be collected from participant observation; documents, records, or journals; focus groups (often considered "group" interviews); and any other method that may elicit rich data from the participants that describe the phenomenon of interest (Patton, 2002). Patton states that a valid approach in qualitative studies is to combine interview and observation techniques, while also mixing different types of purposeful samples.

As already described, this study used purposeful samples of both high and low spatial ability students; meeting part of Patton's criteria for validity. Given his recommendations concerning data collection strategies, it was decided that this project would use interviews as the primary vehicle for data collection. As complementary mechanisms observations within the lectures, a personal researcher journal, think aloud tasks (as part of the second interview), focus groups, and course performance data were also gathered. The following sections outline the procedures used in each collection strategy.

3.6.1. Observation Procedures and Personal Journal

Observations for this study were made within the lectures of the course. The lectures had approximately 120 students in them, and I sat in a non-intrusive location to minimize my presence. I attended lectures in an effort to observe the students and the reactions to the course instructors and course material. Additionally, attending the lectures helped me understand the current content and study problems on which the students were working. This helped immerse and engage me in the environment of the participants, as recommended by Denzin and Lincoln (2000).

During these observations, I wrote notes and personal thoughts in a personal journal. These journal notes were referenced during the data analysis and provided descriptions of overall class reaction and involvement, as well as a chronological description of the activities and content covered each day. Often I wrote reflective thoughts concerning the material covered as well. Sitting through the class often jogged my memory and reminded me of studying as an undergraduate, learning to use my spatial faculties.

Originally I considered not only conducting observations in the lectures but also in the laboratory. However, due to the number of students participating in the in-depth interviews (which were spread amongst 12 of the 14 lab sections) and my own time constraints, only the lectures were observed for this study.

3.6.2. Interview Procedures

The primary data collection vehicle for this study was the use of individual, semi-structured, long interviews. Twelve of the 24 participants were engaged in three 90-minute interviews that took place in a private office setting. The interviews were modeled after the three-interview series described by Seidman (1998). Appendix G provides the primary objectives for each interview, while Appendix I, J, and K provide in-depth information concerning each interview (e.g., interview guides, tasks, or other related background material). All of the interviews were digitally recorded and then transcribed into a word processing program for analysis. After transcription, the digital audio files were discarded.

3.6.2.1. The First Interview

The purpose of the first interview was to garner personal background, life history, and experiences in the words of the participants to complement information that was provided on the background questionnaire. I asked the participants a variety of questions concerning personal experiences (play activities, hobbies and childhood and teenage experiences), academic experiences (favorite courses, teachers, or subjects) as well as miscellaneous experience questions (experience in music, sports, and sleeping habits) relative to their spatial ability. While trying not to lead the discussion, these questions were used as a guide to make sure all the topics were covered with each participant. The questions were not discussed in the same order each time. Rather, I allowed the interview to occur more naturally in a discussion format.

Example questions from the first interview include (Appendix H shows the complete interview guide):

- When you were a child, were there any experiences you can think of that could have contributed to your spatial ability?
- Growing up, did you have any courses, teachers, or subjects that might have impacted your spatial ability?
- Growing up, did you have any courses or particular subjects that were extremely difficult for you?

The interviews typically ended with three metacognition questions (questions delving into the student’s consciousness of their own spatial ability) and an applied verbal-visualization problem that required the students to picture an object in their mind (based upon a verbal description) and then report what they had envisioned. My goal with these summative activities was to discover the student’s perception of his or her spatial ability and whether it was accurate. By giving them an example, it also prepared them for the activities they would be engaging in during the second interview.

It should be noted that students were not told how they scored on the *Mental Rotations Test* they had taken in the first laboratory for CGT 163 (although many did inquire). I acknowledged to the participants that they would receive their score at the end of the semester (along with how they scored on the second MRT test; this would allow them to compare their scores from the beginning and the end of the class). I withheld the student MRT scores so that the interview discussions, as well as the student’s cognition of their spatial ability, would be unaffected by this knowledge.

3.6.2.2. The Second Interview

The goal of the second interview was to delve into each student's approach to spatial problem solving. Prior to the interview, I selected three applied problems, ones that were similar to assignments that the students had completed in CGT 163. The first applied problem required the student to sketch the multiview drawings of the three-dimensional object shown in Figure 3.1. The multiview drawing was moderately complex.

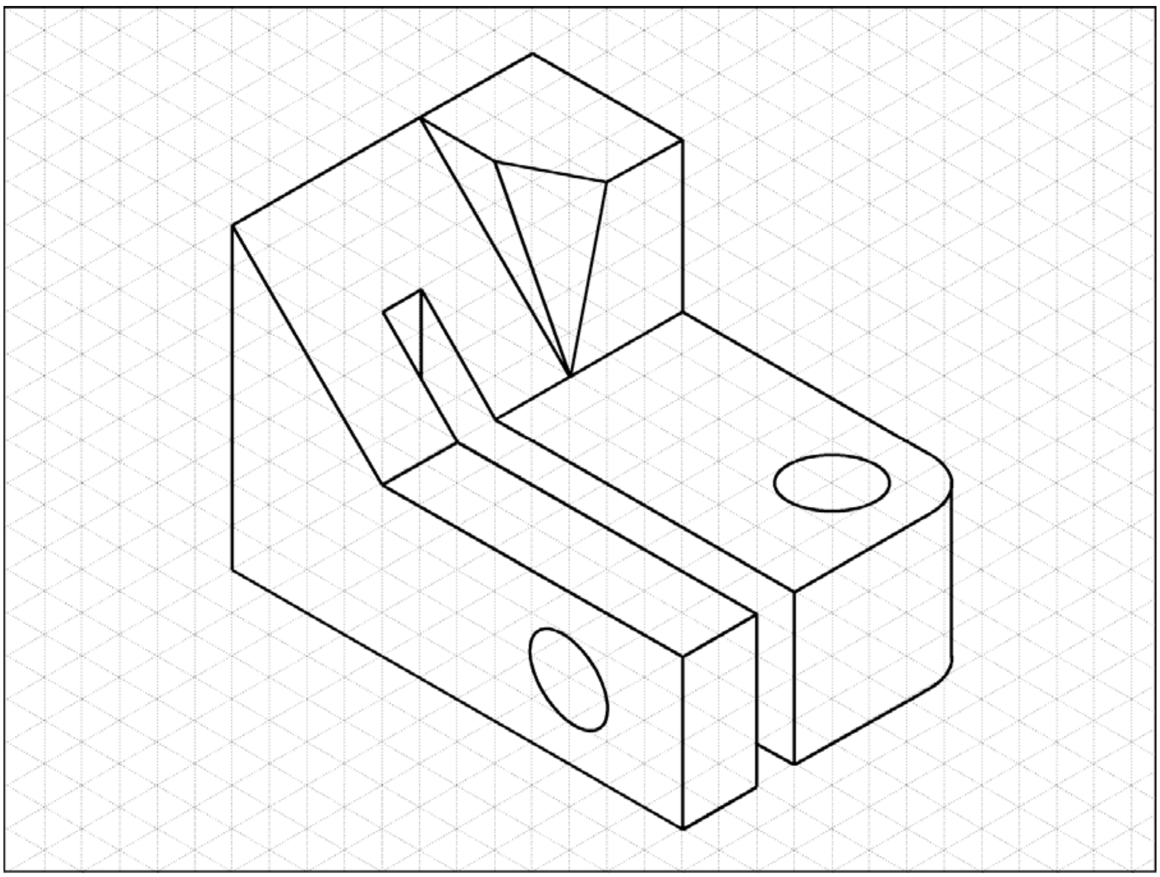

Figure 3.1. The first problem required the students to create multiview drawings of the pictured object.

The second problem required the students to sketch a three-dimensional pictorial object based upon the multiview drawings shown in Figure 3.2. Again, the object was moderately complex.

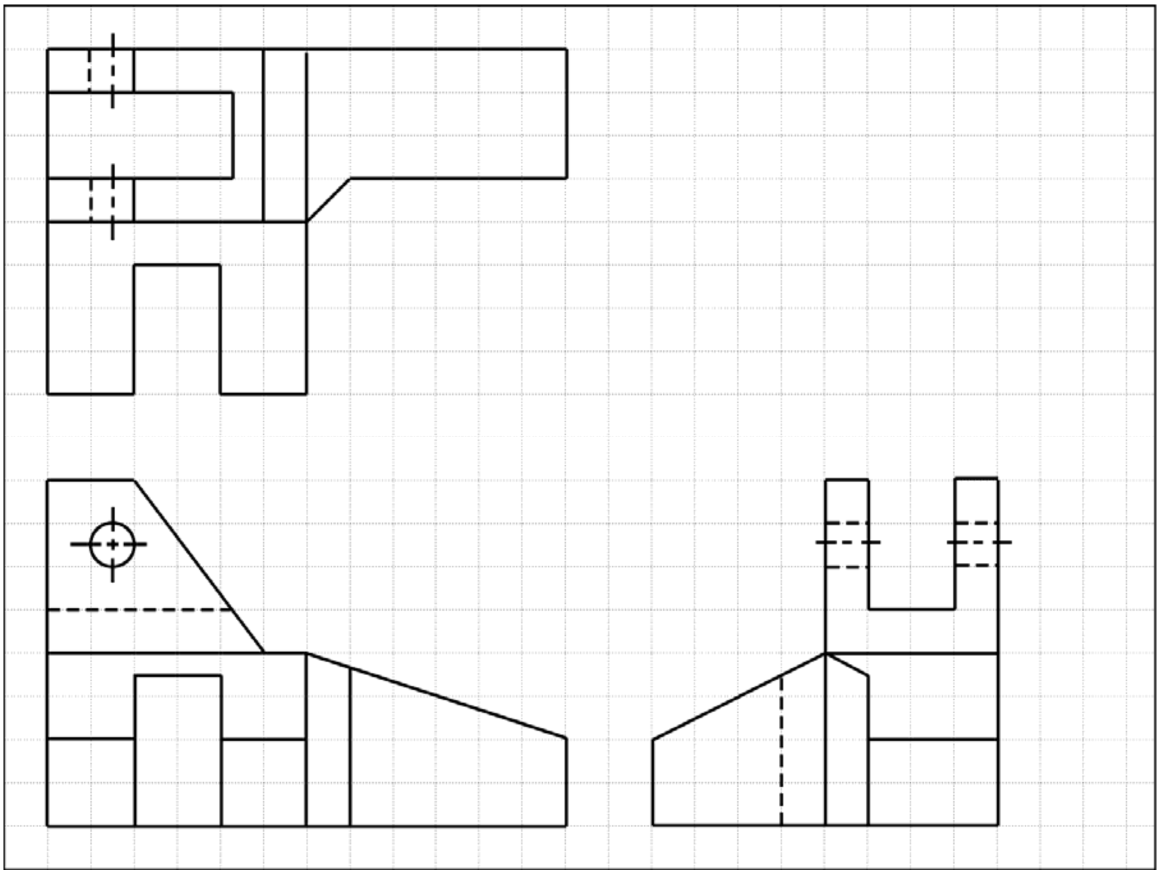

Figure 3.2. The second problem required the students to create a pictorial drawing of the pictured object.

The third problem required the students to visualize an extremely complex set of multiviews (see Figure 3.3) and then draw the three-dimensional pictorial. The last problem was designed to challenge even the high spatial ability students. One-half an hour was allotted to each problem and Appendix I provides the interview guide, which contains the instructions that were read to the participant, as well as several summative questions that were asked at the end of the second interview.

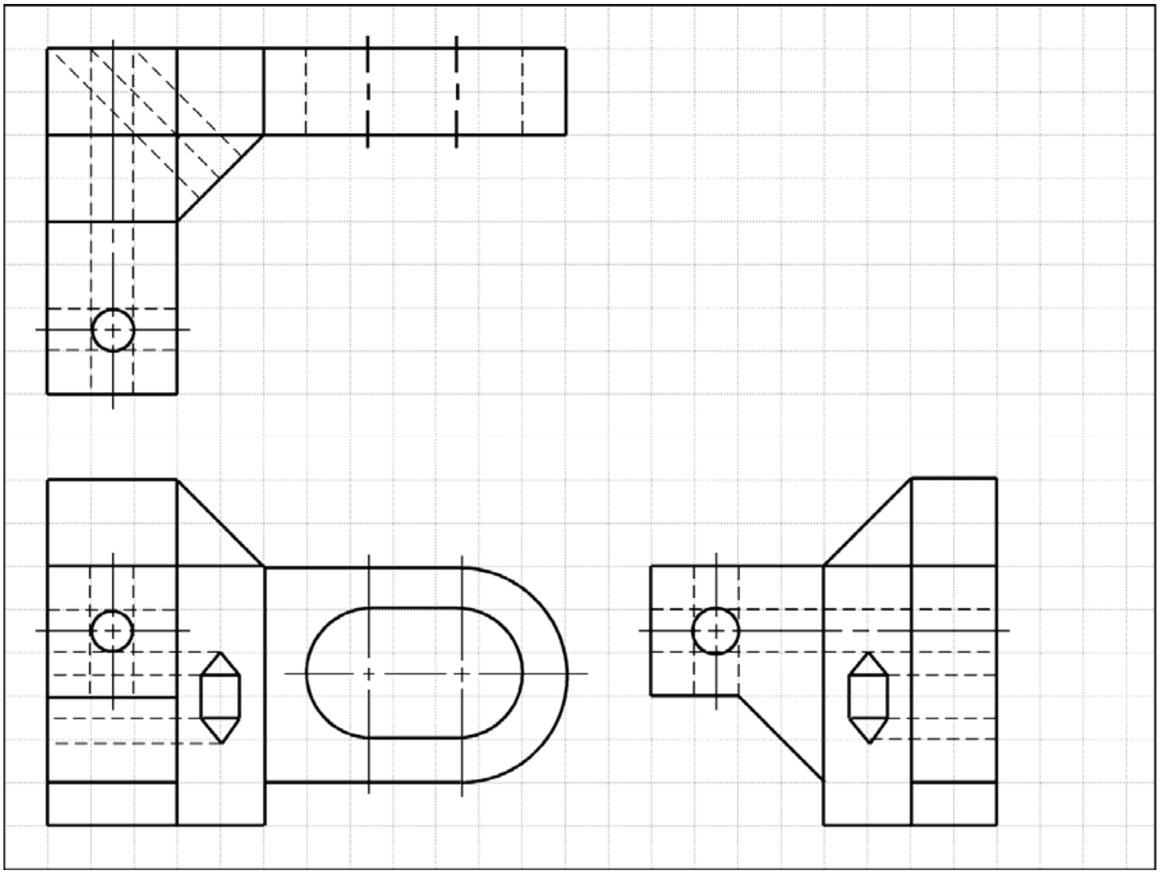

Figure 3.3. The third problem required the students to create a pictorial drawing of the complex object shown here.

During each of these problems, the student was initially given five minutes to study the problem. Then I inquired what they had been thinking about and how they approached the problem. Next, each student was asked to sketch the solution, but at the same time, use a think aloud technique while doing so. At the completion of each problem, the students were asked to reflect on the problem, their solution process, and evaluate the approach they had used.

3.6.2.3. The Third Interview

The third interview was used to delve into the student's attitudes, thought processes, and perception surrounding the activities they had performed in the study and in CGT 163. The third interview also provided the opportunity to summarize the discussion from the first interview, inquiring with the participant whether there was anything additional they would like to personally add or comment on concerning their background or experiences. Example questions included (Appendix J provides the entire interview guide):

- How would you explain to someone else how to visualize the multiviews of an object based on a 3D pictorial?
- Do you have a general process that you follow religiously when doing multiviews?
- What advice would you give to someone who is having difficulty visualizing multiviews? What would you suggest they do to help themselves?
- How do you feel when you are posed with a spatial problem?
- What has been the most frustrating thing for you concerning the spatial things you have done in the course?

3.6.3. Focus Group Procedures

After the in-depth interviews, two focus groups were held in a meeting room. As acknowledged in Table 3.3, the two meetings contained participants who shared the characteristics of either being high or low in spatial ability.

In the focus group meetings, participants were asked a mix of questions from the first and third individual interviews (see Appendix K). The goal of asking the same questions, albeit in a group format, was to see if the groups provided answers that matched interviewee responses. It was hoped that during the data analysis the responses given by the individuals in the interviews would match those responses provided during the focus group.

3.6.4. Additional Data Sources

Additional sources of data for this study were course performance data garnered from the course instructors during the semester, as well as two interviews conducted with the primary instructor for the course. The former served as a means to observe course performance and its affect on ability and attitude of the participants. I was able to use these data throughout the analysis, reviewing participant responses with insight into how they were performing in the course. The latter provided an additional data point by providing the instructor’s views and experiences.

3.6.5. Researcher Epoché Sessions

One of the final data sources that were critical to the data collection was the epoché sessions in which I participated. As described in Chapter 1, these sessions are intended to help the researcher acknowledge openly his or her thoughts, perspectives, values, and biases so that the analysis can be approached from a neutral perspective.

I conducted five epoché sessions during this study. The first of these sessions occurred before the data collection started. It is presented, almost in its entirety, in section 3.6.2. This section presented my global paradigm on spatial ability. The next three sessions occurred before each interview session. Each of these was focused on answering the questions and solving the problems that were to be posed to the participants during the interviews. The last epoché session was conducted after the transcription of the data sources. This last session was aimed at revisiting my paradigm of spatial ability and how it had changed or been affected during the data collection and beginning of data analysis. The remaining four, epoché sessions are presented at appropriate points in Chapter 4.

3.7. Data Analysis

The data analysis for this study was based upon Giorgi's procedural recommendations (1985, 1997). The three major steps in this process were bracketing, intuiting, and describing. The following sections describe the activities associated with each of these.

3.7.1. Bracketing

Following the transcription of each of the data sources (interviews, interview notes, think aloud tasks, focus groups, and researcher journal), I engaged in a final epoché process. The goal of this is to set aside one's beliefs so that the phenomenon can be seen without the shroud of preconception or presupposition affecting it. While the data analysis began with this overt action, bracketing one's perspective is a continuous process throughout the data analysis.

I then began reading each transcript as a whole, examining each for the intentional experience of the spatial ability phenomenon. By reading each transcript in its entirety, I was attempting to get a holistic view of the phenomenon. Development of an understanding of the overall textural descriptions provided a basis the next major step in the data analysis, intuiting.

3.7.2. Intuiting

Intuiting allows one to develop meaning units based on the textural descriptions. This is done by re-reviewing each transcript and giving each statement equal importance. By thinking about each statement and reflecting upon it, I was able to begin identifying meaning units. Here I was looking for the meaning units and their central themes in terms of the spatial ability phenomenon. After identifying the meaning units, I began to reflect on them further, attempting to discover what it revealed about the psychological significance of the spatial ability phenomenon. At this point, meaning units were examined to see if they could be combined or organized further based upon similarity or difference. After I felt I could no longer combine meaning units, I moved on to describing the meaning units using narrative language. This is called the describing phase.

3.7.3. Describing

The last step in the data analysis was to create a structural description of the meaning units, written in psychological language relative to the spatial ability phenomenon. Merleau-Ponty (1962) described the coalescence of the phenomenon (based on the created meaning units) as its structure. Thus, the narrative description of meaning units becomes the structural description. Whereas the textural description of the phenomenal experience is in the words of the participants, the structural description is the narrative that ties together the meaning units derived from the former.

3.7.4. Essence and Essences

The results of Giorgi’s process are the textural and structural descriptions for each individual participant. The combination of these two elements provides a complete expository on the essence of individual experience of the phenomenon.

However, phenomenology aims to provide a description of essences across the participants, rather than a set of individual experiences. Thus, the data analysis continues by interrogating the individual structural descriptions to create a more holistic structural description that applies across all participants. To accomplish this, the researcher compares and contrasts the structural descriptions, particularly looking for the features that are invariant across all the particular cases. The study was originally undertaken for this "essence of essences." It is in Chapter 5 that this summary of group essence is provided.

3.8. Credibility

While the quality of quantitative research typically depends on validity and reliability of measurement instruments (and the methodology employed), qualitative research depends on what Patton describes as credibility (2002). Others, such as Merriam (1998), apply the quantitative terms to qualitative studies. However, Patton's nomenclature seems more widely used.

Patton (2002) acknowledges that the credibility of qualitative research depends on rigorous methods, the credibility of the researcher, and the philosophical belief in the value of qualitative inquiry on the part of the researcher. Patton addresses the issue of triangulation and its importance in establishing credibility also.

The predominance of this chapter has been devoted to outlining the methods used in this study. Nearly all of the methodological decisions I made were based upon the work of respected phenomenological researchers and the recommendations they have made, or on literature that focused upon the entire range of qualitative inquiry. It is hoped that this and earlier chapters have indicated my strong orientation towards the importance of such an approach. Thus, these two issues will not be dealt with further.

However, this chapter has not yet addressed researcher credibility, or triangulation of data sources. Therefore, the following two sections conclude this chapter by discussing these two important issues.

3.8.1. Credibility of the Researcher

Due to my prior experiences within a course similar to CGT 163, spatial ability instruction, as well as my familiarity with the technically oriented student, I believe I had the requisite perceptivity (researcher credibility) in regards to this study. Eisner (1991) states that connoisseurship (perceptivity) comes from appropriate "sensibilities related to the domain of interest" (p 231). Although any researcher can omit something important regardless of years of experience, I have been involved with courses involving spatial visualization for the past ten years. As the first chapter acknowledges, experience bred my curiosity on this subject and led to the questions posed in this study. Additionally, my approach to Chapter 2 was to provide a comprehensive review of spatial ability research, knowing ahead of time it would require many readings in diverse areas. While it is up to the reader to make the conclusions about my credibility, it is hoped that my experience, combined with the exhaustive review of literature will suffice in establishing this important attribute.

3.8.2. Triangulation

The trustworthiness of qualitative research is primarily established by triangulation of data sources (Patton, 2002). It is also established via the richness of description provided concerning participants, the setting, and the researcher (Peshkin, 1993). This study endeavored to provide multiple data sources that could be triangulated and rich experience descriptions. While Chapter 4 will provide the latter, a brief acknowledgement of triangulation used in this study is needed.

Denzin (1978) provides four different ways triangulation can occur in qualitative research. He acknowledges (1) data triangulation, which is the use of a variety of data sources; (2) investigator triangulation, which is the use of a variety of investigators for collection and analysis; (3) theory triangulation, which uses multiple perspectives to interpret a single data set; and (4) methodological triangulation, where multiple methods are used. All these methods attempt to add credibility and trustworthiness to the findings of the study.

For this study, data triangulation was used. Data from different types of sources reveal different aspects of "empirical reality" in qualitative studies

(Denzin, 1978). Therefore, multiple data sources paint a clearer picture of the phenomenon under examination. It is the view of the phenomenon from multiple data sources—when the data sources paint the same picture on the same canvas—that provides triangulation, and therefore, credibility in qualitative research.

However, as acknowledged by Patton, triangulation of sources is not just for confirmation. It also allows examination and exposition of differences as well. Each type of data collection technique is sensitive to different types of nuances. Thus using different data collection strategies allows one to test for consistency but also acknowledge differences. Concerning differences, Patton (1994) states:

> Finding such inconsistencies ought not be viewed as weakening the credibility of results, but rather as offering opportunities for deeper insight into the relationship between inquiry approach and the phenomenon under study (p. 248).

Thus, this project triangulated the information provided via the interviews, observations, focus groups, and think aloud tasks to meet this criterion. Chapter 4 will demonstrate this as I provide textural and structural descriptions across data sources in the presentation of the findings.

3.9. Summary

This chapter has provided an overview to the framework and methodology used in this study. It provided my framework and the specific methods I employed. The next chapter will report the findings from the study. Throughout that chapter, the actual descriptions of the participants and other raw data forms will be used to report what the spatial ability phenomenon is like from the student’s perspective. In addition to the participant descriptions of the experience, Chapter 4 provides the resulting textural and structural descriptions that were verified through the focus groups.

CHAPTER 4. PRESENTATION OF DATA

As described in prior chapters, the purpose of this study was to elicit, describe, and analyze the background, life experiences, and perspectives of individuals with varying levels of spatial ability, attempting to answer the question, "What was it like for a student to experience the spatial ability phenomenon?" The questions central to this research were (1) what do students report as their personal background that could have contributed to their strength or weakness in spatial ability; (2) what personal experiences or academic experiences contributed to their ability or inability; and (3) how do students approach spatial activities given their level of spatial ability, that is, what are their attitudes, thought processes, and perceptions surrounding such activities?

Observation, interviews, applied tasks, and focus groups were used to educe the student perspective of spatial ability; what it is like to be posed with spatial problems. Additional data sources included student performance data in the course, scores on the posttest MRT, as well as the participation of the course instructor.

This chapter presents the data from the individual sources across high and low individuals. It begins by introducing each participant. The chapter then acknowledges the data across each participant, presenting both textual and structural descriptions. It also provides descriptions from the focus group participants as well. While this chapter presents the data, a summation of themes as they surfaced across all data sources will be reserved for Chapter 5.

4.1. Participant Descriptions

The following sections introduce each of the participants. As described in Chapter 3, 12 students were to participate in three in-depth interviews and 12 students were to participate in one of two focus groups. Half of the interviewees and one of the focus groups was composed of high spatial ability participants. The remaining number of participants was low in spatial ability. The determination of spatial ability was based on scores from the Vandenberg *Mental Rotations Test* (MRT), with all high participants scoring 18 or above and all low participants scoring 15 or below. These score "thresholds" were established based on the highest and lowest scores within the group of students who were willing to participate in the study.

In considering the data presented in this chapter, the reader should remember two things. First, the division of high and low ability was a "relative" measure, rather than an "absolute" measure. With all of the participants being enrolled in a technology-intensive course, the low ability students were not representative of a low ability sampling from the population at large. As well, *ex post facto*, I believed three of the low ability interviewees were likely misidentified as low by the MRT exam. Chapter 6 will acknowledge this further and provide recommendations for future studies (such that the low ability participants are more representative).

Second, while all of the interviewees participated in the study from beginning to end, the focus groups had fewer individuals than originally expected. Initially, the focus groups were to have six students each (12 students total). However, in each focus group, two individuals did not attend the focus group meeting. These individuals did not contact me, nor did they provide any reason for their withdrawal from the study. Each focus group was composed of four individuals instead of six and even though two individuals were lost from each focus group, the ratio of males to females in each focus group remained balanced (each contained two males and two females).

4.1.1. Interview Participants

The information provided in the following sections describes each participant based upon data provided on the background questionnaire he or she filled out at the beginning of the study (see Appendix C). Because the first interview included further questioning related to the background of the individuals, the following sections are limited to information provided on the questionnaire only. Subsequent background information garnered from the first interview is provided in section 4.3.

All interview participants in this study were undergraduate students pursuing a technology-intensive degree. While most were seeking degrees in engineering, Participant 7 was an industrial design major, Participant 10 was an aviation technology major, and Participant 12, changed her major from engineering to nursing at the end of the study. For the purposes of the participant descriptions, family income was defined as high (90,000 to greater than 240,000), middle (30,000 to 90,000), or low (less than 30,000). Participants 1 through 6 were high in spatial ability. Participants 7 through 12 were low in spatial ability.

4.1.1.1. Participant 1

Participant 1 (P01) was a 19-year-old Caucasian female who scored 19 out of 20 on the MRT. She acknowledged that her father was an electrical engineer, her mother was a nurse, and that they had a high family income. P01 reported that she was strong in math and that her parents were very involved in her education. She listed her hobbies as swimming for Purdue, watching TV, as well as other outdoor sports activities such as jet skiing, rollerblading, wakeboarding, snowboarding, and riding snowmobiles. She did not report any favorite subjects in school.

4.1.1.2. Participant 2

Participant 2 (P02) was a 28-year-old Caucasian male who scored 19 out of 20 on the MRT. His mother was a homemaker and his father was a lawyer. He reported that his parents were involved with his education and that they had a high family income. P02 expressed a wide variety of interests. He noted that he played a musical instrument, liked to read books, and considered himself strong in both programming and math. P02 had a prior Bachelor degree in business economics. His favorite subjects in school were geography, math, chemistry, and physics. His hobbies included skiing (water and snow), reading, traveling, bowling, golf, and attending sporting events.

4.1.1.3. Participant 3

Participant 3 (P03) was an 18-year-old Caucasian male who scored 19 out of 20 on the MRT. He reported that his family income was high and his mother was an architect, but he did not report his father's occupation. P03 stated that his parents were slightly involved in his education. P03 reported that he played a musical instrument, liked to read books, and considered himself strong in math. He did not report any favorite school subjects.

4.1.1.4. Participant 4

Participant 4 (P04) was an 18-year-old Caucasian female who scored 19 out of 20 on the MRT. She stated that her father was a carpenter, her mother was a nurse, and that they had a middle family income. She believed that her parents were only slightly involved with her education. P04 acknowledged several interests including reading books, writing, Kung Fu, and theatre. She believed she was strong in math, and had always liked science, especially physics.

4.1.1.5. Participant 5

Participant 5 was an 18-year-old Caucasian female who scored 18 out of 20 on the MRT. She reported that her mother was a cake decorator and painter, her father was a truck driver, and that they had a low family income. She also stated that her parents were slightly involved in her education. P05 said she played a musical instrument, liked to read books, liked to write, and considered herself strong in both math and programming. Her favorite school subjects were physics and astronomy.

4.1.1.6. Participant 6

Participant 6 (P06) was a 19-year-old Caucasian male who scored an 18 out of 20 on the MRT. He reported that his father was in agricultural economics, his mother was a nurse, and that they had a high family income. P06 reported that his parents were moderately involved in his education. He acknowledged that he played a musical instrument, liked to read books, liked to write, and considered himself strong in math. P06 reported that he went to a very large high school. His favorite subjects were math, orchestra, and English. His hobbies included running, music, reading, and volunteer work.

4.1.1.7. Participant 7

Participant 7 (P07) was a 20-year-old Caucasian female who scored a seven out of 20 on the MRT. She acknowledged that her mother was a medical transcriptionist, her father was a mechanical engineer, and that they had a high family income. Her parents were involved with her education and she acknowledged having one year of classes at another university before she transferred to Purdue. P06 stated that her favorite subject in school was art and design. While she acknowledged an interest in reading, she listed participation on the Purdue varsity swim team as her only hobby.

4.1.1.8. Participant 8

Participant 8 (P08) was a 19-year-old bi-racial male who scored a five out of 20 on the MRT. Also, he was an international student who spoke English as a second language. He reported that his father and mother were both doctors and they were involved in his education. He did not report a family income level. P08 acknowledged hobbies that included day dreaming, sleeping, music, swimming, and watching TV. His favorite school subjects were math, philosophy, and physics.

4.1.1.9. Participant 9

Participant 9 (P09) was an 18-year-old Caucasian female who scored an 11 out of 20 on the MRT. She reported that her mother was an administrative assistant, her father was a manager, and that they had a middle family income. She acknowledged that her parents were involved in her education as well. P09 stated that she liked to read books, liked to write, and considered herself strong in math. Her hobbies included playing sports and games. Her favorite school subjects included physics, history, English, and math.

4.1.1.10. Participant 10

Participant 10 (P10) was an 18-year-old Caucasian male who scored 11 out of 20 on the MRT. He acknowledged that his father was a service director, his mother was a sales writer, and that his parents were involved with his education. He reported their family income as high. P10 reported that he played a musical instrument and that he was a member of the Army ROTC and the Army National Guard. His favorite school subjects were physics and English.

4.1.1.11. Participant 11

Participant 11 (P11) was a 19-year-old Caucasian male who scored 14 out of 20 on the MRT. He reported that his mother was a secretary, his father was a truck driver, and that his parents were very involved with his education. He reported a middle family income. P11 acknowledged interest in reading books, writing, and he considered himself strong in math. P11’s hobbies included playing video games and playing sports. His favorite courses were history and chemistry.

4.1.1.12. Participant 12

Participant 12 (P12) was a 20-year-old Caucasian female who scored 14 out of 20 on the MRT. She stated that her father was a doctor, her mother was a nurse, and that her parents were very involved in her education. She reported a high family income. P12 noted that she played a musical instrument and that she considered herself strong in math. Her hobbies included running, playing the harp, and hiking. Her favorite courses included mechanics and mathematics.

4.1.2. Focus Group Participants

The following sections introduce the students who participated in the focus groups only. For the purposes of the participant descriptions, family income is defined as high (90,000 to greater than 240,000), middle (30,000 to 90,000), or low (less than 30,000). Participants 13 through 16 were high in spatial ability and were in Focus Group A. Participants 19 through 21 and 23 were low in spatial ability and were in Focus Group B.

4.1.2.1. Participant 13

Participant 13 (P13) was an 18-year-old Caucasian female who scored 19 out of 20 on the MRT. She reported that both her mother and father were self-employed, that they were very involved in her education, and that their family income was low. Her interests included reading books, tennis, and movies. She believed she was strong in math. Her favorite school subjects were physics, history, and art.

4.1.2.2. Participant 14

Participant 14 (P14) was a 20-year-old Caucasian male who scored 19 out of 20 on the MRT. He reported that his mother was a physical trainer, his father was an accountant, and that his parents were uninvolved in his education. P14 reported that his family income was high. P06 acknowledged that he played a musical instrument and had an interest in computers, cars, and electronics. He also noted that one of his hobbies was being a disc jockey. He considered himself strong in math and programming and enjoyed physics.

4.1.2.3. Participant 15

Participant 15 (P15) was an 18-year-old Asian/Pacific Island female who scored 19 out of 20 on the MRT. She noted that her father was a business manager, her mother was in sales and customer service, and that they were involved with her education. She stated that her family had a high income as well. P15 acknowledged that she was strong in math and programming, and she had prior experience in CAD software. Her hobbies included listening to music, being with friends, and working on the computer. Her favorite school subjects were math and science.

4.1.2.4. Participant 16

Participant 16 (P16) was an 18-year-old Caucasian male who scored 19 out of 20 on the MRT. He acknowledged that his mother was a law-firm secretary, his father was deceased, and that his parents were uninvolved in his education. He stated that their family income was middle. While he considered himself strong in math, he listed technical drawing, CAD, and art as favorite school subjects. His hobbies included ATV racing, BMX racing, hunting, fishing, and drawing.

4.1.2.5. Participant 19

Participant 19 (P19) was an 18-year-old Asian/Pacific Island male who scored 10 out of 20 on the MRT. He stated that his father was an engineer, his mother a homemaker, and that his parents were uninvolved in his education. He also reported that their family income was high. P19's interests included reading and cycling, and his favorite school subjects were math and physics. He considered himself strong in math and programming.

4.1.2.6. Participant 20

Participant 20 (P20) was a 19-year-old Caucasian female who scored eight out of 20 on the MRT. She reported that her mother was an accountant, her father was a furniture designer, and that her parents were very involved in her education. She did not report a family income. P20's interests included "anything artistic," drawing, painting, reading, photography, and scrap booking. Her favorite school subjects were art and history.

4.1.2.7. Participant 21

Participant 21 (P21) was a 19-year-old Caucasian female who scored 12 out of 20 on the MRT. She reported that her father was a chaplain and business owner, her mother was an expeditor for an engineering company, and that her parents were very involved in her education. She also reported a high family income. P21's hobbies included playing softball for Purdue and flying (she had a pilot's license). Her favorite school subjects were calculus and psychology.

4.1.2.8. Participant 23

Participant 23 (P23) was a 19-year-old Caucasian male who scored 15 out of 20 on the MRT exam. He reported that his mother was a secretary, his father was an insurance agent, and that they were only slightly involved in his education. He also acknowledged a high family income. P23 noted several interests including playing a musical instrument, reading books, snowboarding, tennis, and golf. He considered himself strong in math and programming, and his favorite school subjects were math and computers.

4.2. Schedule of Data Collection

As the data is presented in the following sections, it is important to understand the order of the data collection events that occurred within this study. Table 4.1 shows the weeks during the semester that the interviews and focus groups occurred. As the data from each interview is discussed in this chapter, the order of the participant interviews will also be provided. The reader should note that the participant labeling (e.g., P01, P02, P03, and so on) had no relationship to the order in which he or she was interviewed. In fact, interviews were scheduled on a first-come, first-serve basis; the order of the interviews varied in all three cases. As additional information, Appendix L provides a portion of the CGT 163 course syllabus as a reference to the topics being covered at the time of the data collection.

4.3. Data from the First Interview

As acknowledged in Chapter 3, the goal of the first interview was to elicit the personal background, life history, and experiences of the participants in their own words. Appendix H provides the interview guide that was used. While acknowledged previously, none of the interview participants was told his or her score on the MRT. This was done to maintain integrity of their responses in the interviews. The questions from the first interview were developed based upon what prior research had suggested was related to spatial ability and its development. Some of the questions included did not yield any fruitful insights, whereas others were highly relevant and important.

Table 4.1.

Dates and Instructional Weeks in Which the Various Data Were Collected.

Data Collection	Instructional Week	Date
MRT 1	Week 1	January 10-13
Interview 1	Weeks 5-6	February 6-17
Interview 2	Weeks 7-9	February 20-March 10
Interview 3	Weeks 11-13	March 20-April 7
Focus Group B	Week 15	April 18
Focus Group A	Week 16	April 25
MRT 2	Week 16	April 24-April 28
Course Performance	Week 17	May 1-5

Beginning with the second researcher epoché session and the background interview with the course instructor, the following sections delve into the data that emerged from the first interview. Table 4.2 shows the order of the participant interviews. While the primary focus was upon background and experiences, in several cases, other unique elements emerged as well. The following sections will examine the first interview with each participant, providing both a textural description and structural description. Those who were high in spatial ability will be followed by those who were low in spatial ability. This section concludes with a summary of the preliminary thematic elements that emerged from the first interview.

Table 4.2.

The Order of the Participants in Interview 1.

Order	Participant	Order	Participant	Order	Participant
1	P01	5	P12	9	P02
2	P04	6	P10	10	P08
3	P07	7	P05	11	P09
4	P06	8	P03	12	P11

4.3.1. Researcher Epoché from the First Interview

Prior to conducting the interviews with the participants, I conducted my second epoché session. As noted earlier in this document, these sessions were intended to provide plainly my background, perspective, and potential biases. In this session, I examined the major areas of questioning and provided my response to them. The following is the second epoché session in its entirety:

> As I think back to my various experiences as a child, there are many that could have contributed to my spatial ability. I lived in the country, not a major or even minor city for that fact. Therefore, I occupied myself with many activities and such that likely influenced my ability to visualize.
>
> As a small child I was always drawing on things-art was a passion in school. I recall my mother telling me that I was always making things, out of construction paper, empty paper towel tubes, actually anything I could get my hands-on. I even drew a fairly decent representation of the Grinch one Christmas on the underside of our living room coffee table.
>
> I recall as a small child that indeed I played with building and mechanical toys daily. Lincoln logs, wooden blocks, and other such toys were my favorites. Most of the time I would build things using Lincoln Logs using the images on the canister as a guide. It is curious that I can even recall some of the pictures though I am over 30 years old today. An interesting thought is the impact of the images that frequent such toys-typically such containers have no ends of "suggested configurations." While Lincoln Logs were all I had, it is interesting to note that most other such toys—Legos, K’Nex, etc. —also provide such images, which likely influence a

child in what they build. I can recall that I often liked to construct things from my imagination. No doubt another potential contributor to the ability.

As I consider how this might have impacted my spatial abilities and realize how often I was engaged in activities that required me to imagine or to picture things with my mind. However, I was not necessarily cognate that I was using these abilities. It was not until I came to college that I discovered that my developed spatial abilities could be quite useful.

I did not have any imaginary friends when I was growing up, but the neighbor kid and I were always coming up with different games. Cops and robbers, cowboys and Indians were typical imaginary things we did together. But more than these, Star Wars and playing with such toys consumed most of our time. This seemed to be a passion we both enjoyed and we would play for hours with vehicles, characters, and such.

I did not have a lot of craft hobbies like woodworking or model building—although for a time I did build some car models. Again, most of the "craft" oriented things I did were aimed at building things out of construction paper and the like.

Drawing, art, and construction type crafts have also been something I have been involved with—now as a teacher of computer graphics it should not surprise me to find myself in my current occupation. I truly believe that it has been my fascination with drawing and art that has constructed my ability to "imagine" something I want to create. Thus likely the reason I have little difficulty with spatial abilities.

Growing up, music has always been a big part of my life—both listening and playing. When I was in 5th grade, I quickly found that the recorder (a required instrument for everyone to learn) was something I picked up quite naturally. This led to several years of playing the saxophone in band and marching band. I also took piano lessons as a child, but quit during my teen-age years. During my sophomore year of high school, I discovered I could sing as well—and that year I played the character Curly in the school musical. Since high school, I have been activity involved in music in one form or another. I have played with a music group for over 10 years.

During high school, I did a lot of working on cars—mine as well as my parents. On my own car, I pulled the engine and did a lot of specific work on it—adding a cam, intake, and so forth. It was not uncommon for me to work for many hours doing small mechanical tasks on my parents' cars

> too—changing brakes, alternators, replacing radios, and so on. All while I was growing up I was very mechanically inclined—it was not uncommon for me to tear something apart to see how it worked.
>
> My favorite subjects in school were art, band, and choir. These are areas in which I excelled. I did have two semesters of drafting in high school and found it quite easy, although I don't remember much of that. Math has always been a subject that I have struggled with, whereas English and verbally oriented courses were relatively easy. I hated foreign language and struggled immensely with it. Also, I never been a good speller and it is only by much practice that I have become an average writer.
>
> The only sport that I was involved with was baseball. I know literature talks about visualization in sports, but I cannot ever recall using my spatial abilities to visualize anything in sports.
>
> I cannot say that I have abnormal sleeping habits—typically, I get 6 to 8 hours a night. I seldom remember my dreams and even when I do, they are "foggy" remembrances at best.
>
> I believe I am relatively strong in spatial ability—but in specific areas. Mathematics has always been a struggle because I cannot visualize equations. But as it relates to mechanical things, visualization has always come easily.
>
> It was not until I was at college that I realized or became aware of my ability to visualize. I suppose it has always been there in the background—but it is not something that I have consciously focused on.

The previous sections highlight my perspectives prior to conducting the first interview. Upon review, my experience in art, craft-hobbies, music, and mechanics appear to be activities that had an effect on my development spatially. Nevertheless, the prior section is included such that the reader may understand my perspectives and background relative to the first interview.

4.3.2. Course Instructor Textural Description

In the background interview with the course instructor (CI), he began by describing his activities and endeavors as a small child. He noted many hands-on activities and being outdoors a lot. He said:

> Well, I was involved with a lot of hand stuff. We lived in the city and on the farm. We moved back and forth. Um, in either case, probably one of the things that I did consistently, unlike a lot of my friends or cousins, we had bicycles; I had a three-wheel, four-wheel tractors. And, I rode the tractor constantly. And, I did a lot of physical activity. I remember sweeping out the barn everyday and that kind of stuff. Toys were almost all hand-type toys. Legos, and um, blocks, erector set...

When asked about other mechanical or hands-on activities, the CI also acknowledged, "Train sets, yes, and HO car sets. Both of those, big time. We had HO car tracks we designed and train sets." He went on to describe a very vivid memory of using hand tools and activity challenges from his father:

> Well the one thing I can remember is there was a TV repair shop that was about three blocks away...he would go down and get TV sets. These are old tube TV sets, and they were junk, but they would still have a picture on them. And, he would challenge us to take these TV sets apart and then put them back together and see if you could still get the picture back. I rebuilt multiple engines, you know, the, the lawn mower engines and go-cart engines and stuff.

When asked if he would call himself a "tinkerer," the CI reported that he would definitely call himself that. He said that tearing things apart to see how they worked was important to him being able to understand them. If he did not approach objects that way he said, he had "issues." He commented, "And it could be big things, houses. Ok? It doesn't have to be on a small level." He was alluding to the fact that he had remodeled an entire house he had lived in previously. Summarizing his childhood experiences the CI stated:

> All that stuff was just interwoven...I am here because of that. I am here because I excelled at industrial arts and I went to Bowling Green to

> become an industrial arts teacher which led to this, led to that, led to here. So it’s all based on those experiences as a kid.

In school, the CI reported that his favorite courses were industrial arts and history. "Nothing else mattered. That was it," he said. He acknowledged that he "didn’t like foreign language" and he "never put any effort into English or the math." He continued, "You know, I, I think part of that was I had some pretty rotten math teachers at a critical ages, seventh grade, eighth grade, ninth grade, just terrible. And I think it turned me off." He also reported the he is "weak" in spelling, punctuation, and grammar.

I then asked the CI pointedly whether he believed he was strong, weak, or in the middle in spatial ability. He said that he believed he was in the middle as it related to spatial ability. He said:

> I would say I was weak at one time, but I’ve had so much exposure to it I'm in the middle...Well simple things I can look at and pick up very well, but if you get into...very complex, um, 2D geometries of like aircraft and some of those parts and stuff involved with that, I have to like sit there and really study it for a while before it actually pops into my head. Just, and I don't know if that’s unique to me or because those things are just so complex, even high visualizers...I kind of wonder if they would have problems visualizing some of this stuff.

The CI acknowledged that he first became aware of his own spatial ability in middle or high school during a drafting class. He said he initially had difficulty with visualizing, but to compensate for his difficulties with visualization, the CI said he would "use labeling techniques and that kind of stuff. Try to identify the planes. Try to break down the geometry into some smaller pieces."

When he got to college and was teaching as a graduate student, the CI had to teach engineering graphics and descriptive geometry. He reported that descriptive geometry was difficult for him. He said:

> I just didn't have a clue about what was going on. I mean, it just looked like a bunch of lines on the paper until I finally figured it out...And what actually helped...I was able to sit down with a professor...and he started pulling out actual objects saying "Well, this line represents the tube," and then once

> he started doing that, then I was able to relate back to something that, that was a physical object. You know before that I was just like, I mean, I could go through and mechanically work the problems and get them right, but I wasn't visualizing them. It was not until he actually started pulling out props that I was like, "Oh I finally see what you were talking about. Now I see what you are doing."

I asked the CI whether he still uses physical props to help himself visualize. He said that when he has difficulty visualizing something, he continued to use physical objects as much as possible. For example, he said, "It’s like trying to work angles on some stuff like on that building I’m building. I'll go cut cardboard out or whatever and try to figure it out and then you know, apply it."

Out of curiosity, I asked the CI if stress ever affected him when he was trying to visualize. Some of the participants had reported that stress, anxiety, and frustration affected whether or not they could visualize. He stated that stress does not necessarily affect his ability to visualize. However, he admitted, "It may have been at one time. There’s really nothing on the line now to make that happen."

4.3.3. Course Instructor Structural Description

The CI’s experiences growing up were based on hands-on experiences that include toys such as Legos, mechanical experiences such as working on TVs or engines, and his ability to know an object and how it worked by disassembling and reassembling it. Spatial ability to the CI is a concept with which he has grappled and studied until he has understood it. However, complex problems still require that he work to be able to visualize. By working with spatial problems in practical ways, and by teaching it, the CI has developed methods to help himself (as well as his students) when they have difficulty visualizing multiviews or pictorial drawings.

4.3.4. First Interview with the High Visualization Group

The following sections provide the textural and structural descriptions for each of the high visualization interviewees.

4.3.4.1. Participant 1 Textual Description

In her introductory interview, P01 acknowledged that playing with building block toys such as Legos were a significant part of her childhood. "Legos were huge. Um...also K'Nex, played with a lot too. That's probably all I played with," she said as she chuckled to herself. She said that with both Legos and K'Nex, she would typically begin by following the pictures or booklets that came with them, but soon she would be off building something from her imagination.

Another childhood activity was what she termed "family puzzle night." She said:

> ...when I was really young we used to have family puzzle night. And we actually built some of the 3D puzzles, the...you know? They're like foam cut...foam pieces...We built the US Capital, the Big Ben clock, and the Eiffel Tower. We built those three as a family. And I think we started like a curved world one time but then it got so difficult because the pieces were curved and we stopped that...So, we did puzzles a lot as a family.

As she grew up, she stated that she did play video games and computer games. She said:

> My dad was big on the...like the computer game that would teach us things like when we were younger...like Reader Rabbit. Or...what'd I play a lot...we played Doom or Descent a lot too, on the computer.

I asked how she approached computer games, that is, how she remembered the levels on games such as Doom. P01 acknowledged that she would just create mental maps, or use landmarks to remember where things were. She said:

> Usually I would like, remember like, "Oh there was something back here I need to like go back and get it." Or, once you've played a while you know like, what corner the bad guy is going to be around. So you just get ready to shoot.

Through her middle school and high school years, P01 reported having some minor experiences with constructing things out of wood and other materials. She was also involved in music; she played clarinet, but stopped due to greater interest in sports. She acknowledged that at about age six, swimming became a focal point for her. As far as sports that she had tried, she said:

> ...mainly just swimming. But when I was a lot younger I also did gymnastics, basketball, baseball. Basically quit those by the time I was 9. And then just been swimming then the rest of my life.

I then asked P01 if she had ever used visualization to help her in sports. She said:

> Well, for big ones [swim meets]...every Wednesday at practice...psyches [psychologists] come in and we...have...visualization...they teach us how to do, well I don't know if they teach us, but at a young age...our coaches would be like, "visualize yourself doing this." But now they are like teaching us like to the second. You can like hit your goal time and visualize it in your head, like if you had a stopwatch in your hand and that would be your goal time basically. You can do that in your head.

Intrigued by her description of using visualization in this manner, I asked her to describe it more fully. She said:

> ...they like tell you, they take you to a place cause they kind of talk you through it the first few times, and they're like "just relax. Take yourself to the pool where you're going to be competing...like what noises would you hear? What smells would you like smell? What would you be hearing? What would your emotions...what would you be feeling?" And then like you visualize yourself like on the blocks...take your mark, go, like swimming. How's I do it is I count my strokes, like I know it takes 15 strokes down the pool. So, I can count those in my head, see myself doing that, do the flip, [and] like come back.

Delving further, I inquired whether her visualization was a first person view or a third person view. She said:

> It depends like how stressful my day was. If I had like an easy day and I'm like, I can see like the bottom...I see like, I'm myself. I see like the line on the bottom of the pool, my hand going in front of my face. But if I have had like a stressful day, I see it in third person. I see myself going down the pool. It's like that's easier I guess to see, for me.

Curious how stress might play a role in visualization, I asked P01 what makes a day hard. She said:

> Like if I'm stressed or not, like if I, how easy it is for me to relax before I do it. Cause I'm supposed to relax first. So yeah, if I can relax or not then it depends on how I can see myself.

Although later in the interview we returned to the subject of visualization in swimming, P01 acknowledged that she had always been in advanced or gifted classes. She said that she had used visualization in a variety of ways. In mathematics, particularly calculus, she used visualization. She also acknowledged using mental imagery to help her in memorization.

When asked, P01 reported that she thought she was average in spatial ability. Sometimes she felt like she was better than others were, and sometimes she felt behind because:

> ...interacting with like people who aren't in like my major,...I think they kind of have no clue...kind of like, the things like I have to do for it...but then I look at...people in my classes and they're just like, seem like they are so far ahead of me, then I'm just like lost. So, I'd probably say I am in the middle.

I asked P01 when she became aware of her spatial ability and she said, "Probably when I was 10 and learning how to visualize for swimming." But she did not know what she was doing at the time:

> ...they kind of taught us to do it as game. Like, close your eyes, here's a stop watch, see if you can like, picture yourself swimming and going this time. And when you are really young, you would like, the stopwatch was

> way faster than it ever should be. So they kind of like gave it [to] us as like a game. But I guess that was teaching us skills to visualize.

P01 said that learning to visualize herself swimming came easily for her:

> I think it was easy for me to picture myself swimming. Just because like, um, I don't know, I guess it, just like, like you picture yourself in a pool and that's what I have been doing my whole life.

P01 reported that when she was young, she would typically visualize the same pool all the time. However, when preparing for meets, she now visualizes the place where she will be swimming. By either going to the Internet to get a photo or by physically going to the pool, she will build a contextual mental image that she can use in her visualization exercises.

P01 went on to describe the importance and frequency of visualization related to swimming. She said:

> ...[for] a really big meet, probably, I'll start visualizing a lot [daily] like, two weeks. I'd do it before I go to bed. Or, if I am bored in class. I'll just like visualize I guess. Just like, um, mainly like visualizing, um, like my start, my turns, my stroke, and when I visualize my actual stroke that's when I'm like looking at myself...like in third person.

P01 acknowledged that she sometimes gets frustrated when she cannot visualize. She said:

> Yeah, if I can't get relaxed, that's kind of like you have to relax before you can do it. Then I'll get frustrated and just give up. Sometimes.

P01 used mental techniques to relax herself. She said:

> I'll like try to relax, try to clear my mind of like, thoughts that don't have to do with like, swimming and visualizing where I am, cause it's usually when my mind's running and if I like, I just try to focus on that.

P01 also reported that her stress could be caused by several things, including swimming:

> Classes, sometimes your roommate, or his shoes...sometimes swimming stresses me out...Just like, um, how you like feel in the water, how you perform in practices, like, how tired you are. Stuff like that.

Prior to concluding the first interview with P01, I asked her to walk me through her swimming visualization routine by visualizing it and talking aloud. She said:

> So I'll walk out of the locker room, like the first thing I see when I walk out of the locker room is all the big ten banners on the opposite wall. I see the pool and...there's like white rope up so you don't get too close to the edge and the officials can be there. Then, when there’s a swim meet, the benches are right in front of the locker rooms. So, I see those. And then, um, I always start off like right now, I don't, I mean the pool is basically empty except for a couple of people, like in the water, just warming up. And then, I'll walk to my left over to the blocks. And then, um, I'll turn around so I am facing down the pool, usually with like, with my hands-on the blocks. Um, I can see that the water is like, it's not quite blue, it's not quite clear. It has like, like I guess it's clear with a tint of blue. The lane lines are thick and their um, black and white. The flags are um, yellow and black at both ends of the pool. The touch pads at both walls are yellow and black. Um, so then I basically look down the pool. I can see lines, and the, I like hear someone say, blow a whistle, and then that’s when you step up to the block. So I'll step onto the block. They'll say like, um, "Women's 500. This is a gun lap event." Then they'll say, "Take your mark," and then "Go." And I'll see myself dive into the pool. I'll take three dolphin kicks off that, off the start. And then I'll start swimming using my legs at the beginning cause it's only a 500. And then, I will take 12 strokes down the pool cause this was off the start. Um, do a flip turn. Four freestyle kicks, take a stroke, take a breath. And then usually there's like, when I stop. And I like think about it or if I am just doing, like the beginning, cause we haven't done like full races yet. So then we'll like, I'll sit there and then I'll think about the finish. So when I have one lap left, it’s a 20 lap event, um, I'll think about my finish and how now that I am. I push off the wall for the last lap and I'm kicking really hard, moving my arms faster than I usually am. So I'll mostly likely take 16 strokes on this, um, length. And when I get to where the flags are I won't take any more breaths, I'll just put my head down and finish to the wall on my side...Usually I visualize myself doing like, um, with my stroke, I'll count to myself, one, two, three, and I like sometimes, I will even move my head cause it's five left and right arms. It'll go one, two, three, four, on my strokes. Like, get my rhythm down. I can usually get it in my head.

4.3.4.2. Participant 1 Structural Description

P01's background experiences could be summarized as hands-on activities with practical toys, such as Legos and puzzles, use of computer learning games, and video games. She believes that these activities, combined with practical exercises in gifted and talented classes, have helped develop her spatial ability. Additionally, from a young age her experience working with swimming coaches, who taught her visualization techniques, have further developed her spatial ability. She acknowledged that she did not always feel confident in her ability spatially.

4.3.4.3. Participant 2 Textual Description

P02 immediately described his primary background experience as a child, which started at a very early age and continues today. He said:

> Oh, by far and away I think probably, I think related directly to this, even when you came and talked to the class, my favorite toys when I was growing up were Legos. And, I always was putting things together and always just building, just whatever it would be you know. It just, it was, I was a fanatic...I had a ton, I mean, just absolute ton of them...I would just cover a ping-pong table. Just complete with constructed things and then I'd have everything, all my pieces to build on the floor then too...when I told my mom that I had been chosen for this [participation in this study], I mean, that was like her first comment was, "Oh my goodness! Playing with all those Legos as a child has really helped you out." Um, but I would say that...building models too. Just seeing how things fit together and being able to hold the pieces...and being able to see it in all the dimensions before you add it to other pieces. And I think then you conceptually get an idea for depth and space.

P02 said he also played video games and did many puzzles (2D and 3D). Of 3D puzzles, he said:

> ...the hardest part about those puzzles...wasn't going to the three dimensional shape. I think that it was, when you found a piece, and you were trying to figure out where it went, it would...I mean, it could be in so many different places around it. I mean it's not like you can just look at one picture of it and see where it is and find it on there...you have to look

> at all the different sides of it to figure out where it went. I don't, I don't think it really was that much trouble for me. I mean, I usually put those together pretty quickly.

P02 acknowledged that his parents put limitations on the amount of TV and video games he could play. As a result, Legos and puzzles became the alternative. He played with Legos incessantly. He said:

> ...man, I mean, it would be like a job almost. I would say 40 hours a week almost. Really, I mean, just, I was a fanatic. Favorite toy...it just, it was just, I mean it was just endless, my parents would just know that they could just put me on the Legos and I would be good. I mean mom would have to call up five times to get me to run upstairs for dinner, just because I wouldn't want to come up.

P02 also reported doing craft hobbies, such as making things out of construction paper, paper towel tubes, and the like. He said:

> ...a card board box was another thing that I definitely played with. You know, get multiples and open up the ends and set on the side and try to tape them together to make long tubes and then, cut holes out of the side and you know, then it would be my space station and whatever, and use markers to draw controls and all that. So I, man, definitely whatever, whenever...we had something around if I was, if I needed something to do I would always be grabbing stuff.

P02 acknowledged that he spent a lot of time around his grandfather, who was a carpenter:

> ...my grandfather actually was really gifted with woodworking and carpentry and stuff, and he would make things all the time. He had like all the woodworking tools you could dream of in his garage. I mean, he would make like games and brainteasers, like the kind of things you find at Cracker Barrel and stuff...he would just see those in magazines himself and make his own version of it to piece together and then give them to the grandchildren and stuff like that. Um, and even, grander scale games we got. One that he made that's got little bowling pins and a top you put in there. But ah, whenever I was around him, when we would go up and visit him, he would sometimes, you know, he'd be out there doing something and we'd go out there and tinker with him and be out there with grandpa and he'd, you know, show you how to lathe something.

P02 had some musical experience also. He played trumpet and a small amount of piano for several years, beginning at age four or five. While reading music was troublesome for P02, he reported that he would often frustrate his teachers due to his tendency to pick up various pieces "by ear." He said:

> ...when I hear songs and stuff, and I hear a tune I like, and then I get around a piano...I can sit down and, if I fiddle for just a couple minutes, I can usually pick up like just the main tune. I mean, I'm not going to get accompaniment and everything, but I can still do it. I still have the ability.

Through his high school years, P02 worked on cars a lot, often with his father. He said:

> ...my dad's got a mustang. So we were always tinkering with it...We actually did quite a bit to it. We put on different exhaust. We put a supercharger on it...and then when we were always swapping out water pumps and things like that if they'd go bad on the other cars...on his car we did all kinds of things, headers, intake. Fascination kind of carried over to me, even now as I am older cause then after I got, I already have a degree...I've got a business degree. And...after...I got a job, went and got a mustang myself. So I've got a 2001. So I've started to do a lot of little things to it as well. So I mean my dad, used to, work at a gas station back when he was putting himself though college, so he was always very mechanically inclined. He's a Purdue grad, too. And he, he had, you know, pretty decent knowledge of mainly lawn mower engines and things like that, but then he could do basic stuff on car engines until now I mean. It's so much computer control it's a little more difficult. So, he was always doing things, and we were always around and exposed to that. So definitely tinkering with cars and still do it to this day. And always, my brother and I would get like, I don't know, probably like eight or nine magazines a month and I mean you read all the technical articles, I mean it's, we're car nuts.

P02 reported that math was his favorite subject. However, he believed that he approached it more analytically than visually. He said that he has often used visualization in physics and engineering courses though. Moreover, while math comes easy for him, spelling has always been difficult. He said:

> Spelling still just messes me up to this day. I am like the world's worst speller. Um, I mean, my spell check on my computer gets worked out

> hard. And, it's bad, I mean, it’s bad, I mean I'm not bad, but when words get longer and complex I am really bad at it. I mean, I know it’s a weakness of mine and I would really suffer without it.

Metacognitively, P02 believed that he was strong in spatial ability. When asked about the MRT exam he said:

> I felt that it was easy. That's not to say that I didn't make mistakes on it and get things wrong, but I felt that, I mean, I would look at it, it just, I don't know, it would just click. I mean, I could look at it and I could almost instantly tell you "All right, that's definitely not it and that ones not it." I mean it, I, I thought it was pretty easy.

I asked P02 how he went about solving the problems on the MRT and he reported using a feature-based approach. He said:

> ...just how when you would see like the blocks going one way and another way. I don't know, just like the feature of itself, like I could look at the next picture over and see that the bend was like opposite. It was like, you know, instead of going to the right, it was going to the left or something like that. That was primarily what I started looking for. I was really just starting to pick one, I mean on there, when some of them would get kind of complex.

P02 reported that he first became aware of his spatial ability when other people made comments about him as a child. He said:

> ...I think I probably hadn't really thought about it much until maybe my mom and my brother and other people started saying to me you’re always good at visualizing things and space and I mean, they...probably would have been around the end of middle school, beginning of high school, so year, I'd say 13 or 14; when they were telling me that.

P02 reported that he sometimes had difficulty visualizing things. However, with time, he can usually figure it out. He provided an example:

> Sometimes when I get some of these problems in class and something’s, the ones that were getting me were when you have a couple of level mechanisms in our dynamics class. Lately, it’s just I get it, it just takes me a moment to figure out how they're going to move. You know, you have

> this lever is turning this way and this other lever is on it and it’s got a slot and there’s another lever, and I'm just trying to figure out how they are all going to move, together...just try to visualize in my mind, well, ok, if this one you know, if this lever rotates this way and you have it going one way, and that's going to push this one and, I mean, you can just kind of see how it’s going to react. I mean, you just start with one piece and see how it’s moving and then you see how the second piece is going to react to that piece. And then you look at the third piece and see how it’s going to react to it.

4.3.4.4. Participant 2 Structural Description

The primary experiences that P02 believed affected his spatial ability were play activities with Legos and 2D and 3D puzzles. He had a wide variety of experience growing up, including computers and video games, woodworking, music, and working on cars. P02 was cognizant of when he was using his spatial ability, felt confident in doing so, and believed that he was strong in spatial ability.

4.3.4.5. Participant 3 Textual Description

When asked about his childhood play activities in the introductory interview, P03 responded:

> Mainly Legos, the ultimate toy... You could do anything with those. I used to have, have like a huge box of Legos that I always did stuff with so...

He acknowledged using pictures and his imagination for his creations, but concerning his thought processes versus instructional pictures he declared, "It was always one step ahead, but it was always changing..."

P03 admitted that playing video games and hands-on activities were a common occurrence. With video games, he said he would typically just remember where things were in the game, as opposed to drawing maps or other techniques. His hands-on activities included something he called "ghetto rigging," as well as woodworking and playing the guitar. Since I was unfamiliar with "ghetto rigging," he explained what he meant:

> Ah, like, if a, your radio isn't working right so you take pieces from a broken radio and try soldering it in and ripping it open and stuff like that, just to get it to work, like duct tape... although I don't, I'd never do that on the level of like a computer or anything, I would, I'd be afraid to ruin something useful and expensive.

As an example, he relayed how he had fixed an old radio:

> ...I guess the speaker blew out so, I had another one that was just, I don't know, it was from an old tape recorder player thing, and it just completely like quit working but...I figured the speakers might still work. They were like the same size, and looked off of one to the other one and was able to get it to work, for a little while.

In middle and high school, P03 found that math became a favorite subject because he "always did better in math." While art and drawing were difficult, P03 did have some experience in CAD, which he thought helped him in CGT 163. He said:

> I had a small CAD-type course in sixth grade, where we just did, um, we worked on 2D sketches. He like, um, like, the guy who ran the woodshop courses at the time also made, he just made a ton of cutouts of small little objects and he wanted us to put it in the top, bottom, and the side view... For the 2D sketches [in CGT 163] I'd say it was a huge help, cause I've only, on those assignments so far, I've only missed on one so far.

Of his educational experiences, P03 reported that he learns much more from applied, practical examples than from theoretical lecture material. He said, "I learn more from like, like five examples than I do from two hours of theorems."

When asked about his own spatial ability, P03 reported that he thought he was strong, based upon the MRT exam. Of the MRT exam, he said:

> It seemed kind of easy but my thought is that maybe when I was in there, I was thinking like, maybe this is not as easy as its looking to me. Maybe I am messing up on something.

P03 reported using a comparison approach to the MRT exam by examining specific features of the objects to determine similarity or difference. He also reported using his hands to help himself visualize. He noted:

> Sometimes I would like try to rotated it with my hands, sometimes I would just draw a line in, I mean, my steps. Really, I didn't do more than a which one matches or doesn't match and cancel that out. Usually I could always find one simple point [on the object for comparison].

P03 acknowledged that he did get frustrated when he could not visualize something. To overcome this he said he had to:

> ...look for examples. If I can't find any, then I have to go through all the theorems in the book; how it's listed, try to piece it together. I could usually get it most of the way, but I usually couldn't, being off in the end, I have to seek some sort of help whether it's, you know, looking thoroughly through examples for one small piece, or having to go ask somebody for help.

4.3.4.6. <u>Participant 3 Structural Description</u>

P03's primary childhood activities were focused around hands-on, practical endeavors such as Legos and working with (and fixing) small appliances. He was strong in math and preferred that subject in school. He believed that he was strong in spatial ability. Sometimes he lacked confidence in his spatial ability and sometimes he got frustrated not being able to visualize. However, he was self-aware and knew, based upon experiences in other areas, what he needed to do to help him understand and overcome course content difficulties. For his practical nature, examples were the most needed element for him to understand difficult course material.

4.3.4.7. <u>Participant 4 Textual Description</u>

P04 acknowledged that she was a very active child, trying many different activities as she grew up. She said:

> I tried pretty much everything. Ballet, and ah, tap, and ah, gymnastics, soccer, softball. I played piano for a little while. I never stuck with anything for very long. A lot of different things.

P04 reported that her most frequent play activities were imaginary stories with Barbie dolls. She said:

> I was a Barbie fanatic, I have like, I still have all my Barbies stuck in a box down in the basement. I got like 30 or 40 of them. That's what I did all the time.

She said she also liked to play with blocks. She recounted:

> ...when I was really little I loved to play with the big thick wooden blocks and put them together. I always wanted to put something together that was really, really, really big. So... when I was in preschool...I took every single block that they had in the room and made this gigantic structure in the middle of the room and I wouldn't let anyone else play with these blocks. I took all of them and the teacher was so impressed by it she called my mom up and had her take a picture of it. It was pretty cool.

After she discussed this story, she acknowledged that she would often get lost in activities such as playing with Barbie dolls or blocks. She admitted:

> ...I used to just get lost in activities like that. And just decide, "Well I'm just going to keep going and I'm going to move over here." I painted my whole arm once because I just forgot what I was doing!

As she got into high school, P04 got involved with theatre set construction and lighting. She said that her father was a carpenter and that she learned how to construct things from him at an early age:

> I tried to, to make a coat hanger once. Like I took a block and put a bunch of screws in it, and I thought that would be a great coat hanger, but, I didn't usually have a whole lot of direction a lot of times. I was just helping my dad make something... I started going when I was probably six to eight-ish and at that time, he didn't really give me a whole lot of stuff to do. It was kind of like, "You want to bring me a tape measure?" And...but then as I got older, he would let me use some tools and then when I got into theatre, I really started learning to use all the different power tools, and the

> saws and the drills. He would actually be like, "I've got a project for you. Could you go cut that for me and then ah, put this together?" and I would actually, he trusted me so that I could actually use the different tools and do projects for him and then we would put ours together.

She believed those experiences are what got her interested in theatre set construction and design. Over time, she found a particular technique helpful in pre-planning sets:

> ... the best way I figured out of doing it is make a little three dimensional model out of foam core and then you can kind of see, "Ok is this actually going to stand up here?" And then, pretty much through experience, I was doing that for four years, I had learned a lot about ah, how to brace things properly and you know, what, what kind of what is a good idea to make a platform out of like. You never want to use Luan. You want to use three-quarter inch ply for somebody to stand on. And, so a lot of just experience and having built so many sets and worked on so many things. I just kind of, knew how things should be built, should be constructed to be safe and look right. Making the little models was helpful so I could actually see, "Ok, yeah. That's actually going to fit there" and "No, we can't move this piece like that so I am going to have to figure out another way of creating that."

P04 also acknowledged a time when she had difficulty visualizing a theatre set and a solution to a particular problem:

> ...I had this one show called *Fools*. There was, it flip-flopped back and forth very quickly from being inside and outside. So I was trying to, to make the inside really small, and the outside really big and I couldn't figure out how that was going to fit onto the stage and how people were going to be able to act in it. And I really could not figure out what to do about, with that situation. I built a model and it just looked terrible. And it was like I have no idea how I am supposed to put this together so it's actually going to come out so we can use it... I went to the director and I was like, "I don't really know what I need to do here to make this better" and so she kind of gave me the idea of making these, flat walls that pivoted. Turned out to be a really disastrous idea, because they were top heavy. So in the middle, so at the last scene change of the last show, it fell over. And it was pretty, bad. I didn't have a very good night that night.

In addition to her theatre experience, P04 reported that she tried to play both piano and clarinet but found reading music and practicing very difficult:

> I can’t read music very well at all. I'm really bad at it. Like, I really did try for the piano for a while and I really tried to learn all the notes but I couldn't. I couldn't remember looking at the scales, like which one was which. I would have to sit there and think, "Ok, that's G" and I had to count and it was, it was just really hard.

P04 declared that she really liked science and math in high school. She said she really liked the "discovery" aspects of those subjects. However, she did acknowledge that at times, both subjects could be difficult. When she encountered a difficulty in math or science, she said that practice was critical for her. She acknowledged that she typically used an analytical approach, combined with sketches or drawings:

> I have to go piece by piece. I can't start looking at the whole problem, because it is overwhelming. I have to go, "Ok. This is where we start," and that’s the next piece of that, and that’s the next piece of that, and just kind go individual and work my way...I like to draw a little sketch of what is going on and that usually helps me figure out, "Ok. This is what we need to do. This is how...the relationship...is happening here.

P04 also articulated her weaknesses. She said that she was a slow reader and that the "memorization of dates and things" was difficult her. Spelling was also troublesome for her:

> ...spelling has been horrible for me my whole life. I'm still always, I've got my dictionary sitting right up on my desk so I can always refer to it. And I love spell check...I can’t spell to save my life... my mom took me to a phonetics teacher once, and she doesn't think I can hear the difference between consonants and vowels, like...in words...[where]...you’re not really sure is that an "i" or an "e." I can’t really hear the difference or something. I really don't think anybody can, but I'm not really sure.

Of her own spatial ability, P04 believed that she was strong, which she attributed to her construction experience, playing with blocks, and drawing. She said that spatial thinking was a "pretty natural thing" for her:

> ...like if I start reading a problem and it requires spatial thinking, that's what I do. And then, if it’s troublesome, I start drawing it. But, if I can think

> it through in my head, I'll do that first and if I need to, I'll draw it out. But really I've never thought twice about it.

4.3.4.8. Participant 4 Structural Description

P04 attempted many different types of activities growing up, but ones that occupied most of her attention were playing with Barbie dolls and blocks, and helping her father with construction tasks. As she acknowledged, she can get very engrossed in certain activities. In high school, her set design and construction experience was a critical part of her life and developed her spatial ability. She was aware of both her strengths and weaknesses. She found that spatial thinking was quite natural for her.

4.3.4.9. Participant 5 Textual Description

P05 declared that her most frequent childhood activities were playing with Play-Doh, Legos, and Barbies. She also did a lot of finger-painting and reading as well. She relayed a particular memory of playing with Play-Doh as an example:

> I always tried to make real things. Like this one time tried to make a beehive and I couldn't, how I was going to make a beehive. So I like made a fist and wrapped my hand with Play-Doh. All except for right where my wrist was and then I tried to pull my hand back out. And I kind of closed it up and put little pieces inside to try to represent honeycombs. I just remember that because, I don't know, I felt so lame when I was a little older playing Play-Doh again remembering when I used to try to make little beehives...I'd always try to make something, little flowers or houses. I made a lot of houses.

When her brother got old enough, she said a common occurrence was for them to play with Legos and other such activities together:

> Yeah I played with Legos, but mostly once my little brother was born we'd play with Legos together. And, we'd um, we went over to my babysitters a lot and she had, she had a bunch of Legos, and do you remember those

> little cardboard bricks? She had a lot of those. So we would, would make these huge houses. We would all try to make castles and everything out of all these Legos and bricks, because there was a whole bunch to use. There was at least five or six of us and everybody would be like, "Ok. I'll make this wall." "Ok. I'm going to try to make a chair," but it never worked. But, they always tried to make a chair. Yeah that never happened.

P05 recounted that she did many construction activities also. She told a story about a less than successful activity, too:

> ...because my mom and I watched a lot of Sesame Street. Oh, we do most of those things. Um, yeah. I definitely made the binoculars, and this one time, oh, I decided I wanted to be like Thomas Edison, and invent the light bulb. And I took the tweezers from an Operation game and a Ziploc baggie and a paper clip and a nickel I think. And I built this light bulb and plugged it into the wall... The fuses blew.

In middle school, P05 got involved with academic competitions (Academic Super Bowl and Science Olympiad), art, and music. Science, particularly astronomy, was her strength. Because of that, P05 had a very broad interest in space—concepts such as string theory and other universe-related concepts. She noted that she often thinks about such topics spatially. She described:

> I see it, I think, pretty concretely. I know that the colors that are there are fed to us by NASA, but don't have too much else to base it off of...I can, kind of zoom. I picture the asteroid belt as just a bunch of rocks floating around. I can take my myself beyond that and see, you know, our galaxy in relation to this. Yeah, I think about it visually.

P05 acknowledged that she not only thinks spatially but also tries "to take things apart" to create an understanding them.

Her interest in art, on the other hand, was primarily due to her mother:

> ...the biggest reason because my mom likes to paint. She also has a lot of her watercolors on display in the library and in my home. Um, so she always had a bunch of her paintings hanging around and when I'd get stuck she'd help me and I know I picked that up from her. Because she really loves to paint and she's really good at it in my opinion. But of course she's my mom. But other people think she's really good too.

P05’s interest in music began during this time as well. She said:

> ...clarinet was really easy because um, I had taken violin lessons in 4th grade. So I already knew how to read music and understood the basic concept of notes and that sort of thing. And, you know, they teach you recorder when you are in elementary school. You know. That was always a little bit complicated for me. The recorder wasn't very good.

In addition to these experiences, P05 reported that she had gotten some CAD experience in high school. She said that because of that experience, she found the sketching assignments in CGT 163 relatively easy. In normal everyday events, P05 believed she was quite good at spatial problems, but she noted that tests such as the MRT that are abstracted from reality were more difficult for her. She said:

> Ok, if we talk about the mental rotation, that's a little more tricky just because it's just a bunch of blocks. And it's on white paper with black lines so, I don't think that it’s, it’s obviously not impossible. It’s more complicated than normal spatial reasoning in the physical world. If you have, say you are packing to go home for the weekend and you have all of this stuff and this tiny trunk to fit it in. You can kind of get an idea of what you're going to put where so it will all fit. "Ok. This I can turn and put that there." That's easy. Just kind of, ok...and my roommate has a really hard problem with that. She can't get everything in her trunk, and I'm like, "Ok, stop. Put this there, put this there, do it." Fine. On paper, I can still do it but it’s more difficult than 3D manipulation of objects I believe.

She relates her first practical recognition of using spatial ability in much the same way:

> I’d actually say that it was some point when I was a lot younger, because we have a very small house. And I had basically one closet where I could put all my toys, and I always knew that everything was going to have to go back into that closet, somehow. And, I would always be trying to figure out, "Ok, how does this have to be turned to get in there?" And I knew that that was what I was trying to do-trying to figure out how to turn things so they'd fit somewhere.

She said that this task was a daily occurrence, and that it likely affected her spatial ability. She recognized that she was visualizing how to do it in her mind:

> I'd always get a picture first. I would always start with something. I can't just start throwing things in there, cause that won't work. But you just kind of, you pick the big things and you try to figure out [how] they'll be oriented so they'll all fit in there. And then you take the smaller things and you try to see how you can orient them to fit in the spaces in between. You know? And...that's pretty much it.

When asked if she is ever frustrated by not being able to visualize something, she said "sometimes." She continued:

> I sit there for a long time, and try to figure it out. Something like that [visualizing string theory], eventually I got to the point where I decided I needed to plug ahead and see if he would say something else that would make it fall into place for me. And eventually that did kind of happen. I can't just give up right away. You have to struggle with it. It's a lot like, a lot like studying for everything here. You just don't understand something, you can't just give up. You have to read the textbook. Try to puzzle through the problems, and try to figure out why. I have to know why, I can't just figure out what I am supposed to do, because to me that is the same thing as not knowing what to do, because you don't know why you are doing it. For math, that's a good example, today we are doing trigonometric substitution, and I understand what it is we are doing...[but]...I don't know where it comes from. So I have been puzzling through. Going through the book, I am going to go sit in the math help room when I am done here and ask, ask somebody. If not, I am going to sit there and try to figure out why they can use these trig identities and how they know which side of the triangle is going to be which.

I inquired with P05 what it was about the "why" that was important to her in figuring such things out. She said:

> I find it a lot easier to know things if I understand why, because if you forget something that you have memorized, you can figure it out again...I am definitely a big picture person. When I read through a story problem for the first time, I will skip over the numbers. And I will just read "Ok. I know the coefficient of friction. I know the angle of this incline. I know the mass

> of these blocks, and I am finding this." Then I'll go back and...[get the numbers].

P05 went on to say that, it was during the current academic year that she learned that about herself-that she had to know the "why," not just the "how," to be able to understand something.

4.3.4.10. <u>Participant 5 Structural Description</u>

P05 believed that her childhood experiences with Play-Doh, Legos, blocks, and craft activities affected her spatial ability. She believed she has a strong practical spatial ability, but when abstracted to a test such as the MRT, she was unsure of her strength. She believed there was a construct disconnect between the MRT and practical applications of spatial ability. Also, she highlighted that the "why" of learning was as important to her as the "how." She was very aware of her own learning. For her, struggling with problems ("puzzling through" them, as she called it) was an important part of the learning process. She seemed to exhibit mental maturity in her ability to move past material that confused her (believing she would figure it out later in the process) and for her need to know the "why" not just the "how."

4.3.4.11. <u>Participant 6 Textual Description</u>

When asked about his childhood play activities, P06 said, "I was a Legos, video games, and outdoors kid." With his Legos, he said he "had a lot of kits" and that he would follow the pictures that came with them, but he would also do things from his imagination. "I was just like, I mean, an hour a day or so I would be playing with them. So it was whatever I felt like usually," he said.

The video games that P06 played were adventure type games. Although he did not draw maps to help him play the games better, he said:

> I'd buy all the magazines and stuff and they...I remember, especially the old stuff, when you could just print out the maps [from the Internet]. So I would always look at those and like try to visualize like how the levels are set and things...I do remember doing a lot of that. But, when you're just playing it, you're just kind like going with it. But you memorize the levels and they were kind of easy too.

P06 admitted he did a lot of model building too. In relation to the small picture booklets that come with models and Legos, P06 said:

> ...I really, I really think it's because of being a Lego kid and growing up with the little booklets or, they're all done or drawn in isometric form views. So like, I was constantly, I grew up with all those so it was really easy for me to transfer it to, you know, like a modeling building kind of thought process.

P06 remembered doing construction-types of things (with cardboard boxes and paper towel tubes) as a child also. He mentioned:

> I remember a couple of times when I had done a bunch of things. I would find a bunch of cartons and stuff. I remember I would like find boxes and stuff and I made a whole town at one point. I built this like little town. It was pretty big. I was kind of surprised how gargantuan it grew, but ah, there was a little section base and I'd take like the, I don't know just whatever I could find and milk and paper towel tubes. I think it was something I saw on Mr. Rodgers show, and I thought I would just try something.

As he got older, P06 started playing the string bass, which led to learning the bass guitar and piano later. He started playing when he was 11 and took four years of lessons. He disclosed, "I pick up instruments a little more easier than the average Joe on the street, so I just, cause I've been around music for so long." Because the transition from bass to piano is difficult, I asked P06 how he taught himself the nuances of piano music versus bass music. He said:

> Ah, it was a challenge at first. I'm going to be honest with you, but, I just, I just kind of thought about it mathematically. It's like you know, it's um, bass clef, I mean treble clef is just two steps up from bass. You just kind of like, just rearrange the notes in your mind and you can easily kind of figure it out... then once I could just get to the point where I could be comfortable

> with the treble clef, I won't have to think about the relationship any more I can just kind of like...[play]

P06 said it took him about three or four months of playing piano before he did not have to think about the music.

During his school years, P06 found that his favorite subjects were math, fine arts, and history, whereas biology and chemistry were difficult. He said:

> ...chemistry and biology. I think the main reason is there's so many rules and there’s so many exceptions to the rules and things like that, that I just have trouble with it. Like it’s, kind of like, there’s a ground rule but there’s nine other subrules to it. So it’s like I just don't do well with that type of logical reasoning and if I can't really visualize how things are working, and a lot of chemistry is like really tiny molecules interacting with each other, and you can't see that in real life...so I would have a lot of trouble connecting like, the properties and stuff because it just wouldn't make sense. Because I couldn't really visualize how it works, I would just kind of like have to go by what they say. So that would give me a lot of problems. Biology, the same way. It's just lots of weird stuff that can't really visualize. You just kind of got to trust the guys who do research. So I just don't do, my brain doesn't work well with that kind of stuff.

Spatial thinking is now critical to P06. He acknowledged a very good teacher that he had in high school that helped him think visually. He said:

> I took an engineering [course]...in my high school and we had to use, this Inventor program and [I] really hadn't used any...[programs]. So he, my teacher, Mr. Wilkins, he really like ah, like forced me to really think spatially and things like that...at first I had a lot of trouble...with thinking like that. You know, I'd get on the program and get all confused in three dimensions and stuff. You know, he really helped me...to kind of, to make solid rules in my head when messing with three dimensional objects. So that really helped...we'd do multiview drawings but we would also have an object that he'd be like, "We have this object designed, put it, put this exact object into the computer"...[we would] just put them into the program in the computer and like building, you know, like assemble it in the computer and then build it in real life. So just lots of different, like, really try to stretch how you think about things.

P06 described being involved in football and track in high school also. In track, he threw shot and discus. He said that he was taught to use visualization to improve his performance. He recounted:

> I know a lot with throwing we would visualize the throw. That was huge. You would like, you'd really have to, cause throwing happens so fast. You can't really think about what your feet are doing or what your body is doing. You got to just, kind of just, you have to practice each part and kind of put it altogether in your head and do it. So I remember, we'd do visualization drills where we just kind of sit and think about the throw and think about our foot position and think about, you know, really slow it down in our heads, what's going on, before we went out and did it. So I mean you have to visualize that. Then with football, I know we would have to really visualize um, like the routes you're taking and kind of try to visualize what the, you know, other players are going to be doing so you can see like where you need to be if it's the right time, right moment to, you know, to run the play correctly and things like that. So, you know, had to do a lot of prior visualization and in both sports.

P06 acknowledged that he used visualization often in track practice. He would think about how to do it, or how he had done something wrong, to help himself get better:

> I would do them a lot, um, during practice. Right after I throw I would kind of go over the throw in my mind, and try to um, or like think, you know, the coach would say you're doing this wrong and think about how it should be or where my foot should be and things like that. And then during meets, um, just right before I would throw, I would just visualize kind of what I want to do in the ring and kind of how, how much spin and how much, when I want to push and all the different things I want to do during that specific throw. So I would use it a lot...

I inquired whether P06 ever found his body reacting to what he was trying to visualize. He responded:

> Oh yeah. I was a dork. I looked weird when I was out there thinking about it. Yeah, I'd usually, my feet would get involved with it, or I would start pushing like how I was supposed to and ah, yeah, I would get into it. Cause you just have to get pumped and really give it 100 percent before you go to give it 100 percent when you throw.

In thinking about his own spatial ability, P06 reported that he thought he was average to high in spatial ability. He acknowledged:

> I'm probably in the middle or a little more toward the strong, definitely not strong. I get kind of hazy sometimes. Sometimes things get kind of confused in my mind but, um, I do think I can visualize things a little better. Just kind of the feel and layout a little more than the average person.

He also admitted that how he feels could affect whether he could visualize:

> I think it just comes down to, if you are tired you're not going to think well or if you're stressed. If I'm on top of the ball, it's usually a lot better than if I have not been sleeping and stuff like that.

P06 acknowledged that people have told him that he is good at visualization before. He recounted:

> ...someone made a comment to me once, like um, you know, we're putting together this, like later on in life, we were working on a Lego set and I was working with some kids and they were having a real hard time. This may have been my freshman year and we were doing it for some project or something. They were having real trouble like looking at this booklet and then transferring it into real life. I don't know, it made no sense to me. I'm just like "This so easy, like you can just like totally tell." So I think that's when it really hit me that, you know, I can visualize things a little bit better than most people. Just, I don't know, maybe I have had more practice with it or what not, but you know, here's just, I can just see how things are supposed to be at the end of the project a little better than people who just kind of can't see that stuff as well.

P06 also reported that he sometimes had difficulty visualizing "really, really, really complex things, like...huge objects." When that happens, he tried to break the problem down so that he could process or visualize it. He said:

> I just kind of cut it into pieces. Like, whatever I am focusing or working on right now. This will be all I think about. I won't work out the rest of it, and the rest of it will take care of itself. It's just like I'm working on this part and then I kind of have a vague, you know, understanding of what the rest of it is. So, I mean, I remember especially, we'd get really big projects in um, in engineering class that we would have to put on computer. So on computer, when you're doing it, I'm like, "Ok. I'm working on this section

> and I know how the rest of it is supposed to be, and I'm going to make this section so it fits in the rest of it, but I am not going to think about every little detail. The rest of it I'm not going to worry about. Just visualize this part. Then visualize the next part and then kind of, just assemble it all together at the end and make it all fit."

4.3.4.12. Participant 6 Structural Description

Primary childhood activities for P06 included Legos, model building, and construction paper activities. As he grew older, music became a significant part of his life. P06 had a significant learning interaction with a high school teacher; one he believed helped him learn to think spatially. Looking back at his experiences, P06 could see where he had used visualization in certain activities, such as sports, and recalled a time where he realized he had high spatial ability. P06 acknowledged the ability to break problems down to help solve them and had the ability to overlook a lack of holistic understanding of a problem; tackling the pieces that he could understand.

4.3.5. First Interview with the Low Visualization Group

The following sections provide the textural and structural descriptions for each of the low visualization interviewees.

4.3.5.1. Participant 7 Textual Description

At the beginning of her first interview, P07 acknowledged that she played with action figures frequently as a child, often imagining various scenarios:

> ...Do you remember Play Mobiles? They were like little figurines. I used to love those and I wasn't very into the Barbies and that kind of stuff, but like I had like this house thing and, and the Play Mobiles. It was really cool...it would be like this is like, this whole world and my figures would be in the world with my brother like, he was like, 2 years older than me and we would like play that together.

While she did not play with mechanical or construction toys, she said that she was also into craft hobbies, such as modeling clay, beads, drawing, and coloring. Of craft hobbies, she admitted:

> Yeah. Everything. I love like making stuff, like those little bracelets, that was a huge thing when I was younger, like making all the different kinds, like I had books to show you how to do different, ah, techniques of those little bracelets, but...I like doing that...there were these ceramic things that were plain and I would paint those when I was little, but I haven't done that in a really long time but...yeah. I like doing all that kind of stuff.

P07 said that she played piano and drums through the fifth grade. In her private school, playing an instrument was required. After learning the Flutophone, she took piano lessons and then played drums. She commented:

> ...well I was actually kind of bored like doing [drums]. I really didn't like doing that part of it, like, I kind of liked the piano thing and I liked the more independent thing. I didn't like being in the whole band thing, but I had to...

P07 has been involved in swimming since the second grade. Although in her early years she tried many different sports, the independent nature of swimming attracted her more than other sports. During middle school, P07 got actively involved in swimming, which became her primary focus from that point on. She recounted, "In middle school, well I'm a swimmer so, I basically quit everything, doing all that other stuff and just basically went into swimming..."

In regards to swimming, P07 said that she had been taught to use visualization to improve her performance. She said:

> ...well we were taught a technique, well like, I was taught it a long time ago, you know, of like close your eyes and relax and think about like your perfect race and how you would want to swim it. And, then you try to do it. The better you get, you try to do it real time. And, um, when I first started, I was kind of visualizing um, like as if was like I was watching myself on TV like I could see myself swimming it [a third person view]. But, now that I'm getting better at it I'm more, it's more like in my head [a first person view]. It would be like actually if I were swimming it, like what I would see and like it, going through my head.

P07 reports that her swimming visualization included specific details like the number of breaths and strokes in one length of the pool, as well as a sense of rhythm and timing. She elaborated:

> Like I can think, like, with my breathing. If I am going two up and one down, like two breaths and then one down like that, and I try to think of my rhythm and I mean, I've gotten pretty good to the point where like, if I hold a stop watch, I can start it and when I'm stopping, it’s the time I really want to go and you can, I think about like. My underwater kicks, how many I'm going to go, what pace I'm going to go at, and stuff like that.

P07 stated that she goes through her swimming visualization at least once a day, typically before she goes to bed.

> ... every night right before I go to bed I go through it once at least perfect. But like, it takes me a lot to go through it once perfect. Like every time we do it, like, sometimes I get distracted or sometimes something won’t be perfect and I’ll start over and do it again. But I make sure I get through it at least like one full race really good and then um, during the day like if I'm just bored or if I have something to think about, I try to like, to picture different parts, like the start of the turn or stuff like that. But definitely once a day like I make sure.

P07 confirmed that visualizing the beginning of the race is easier than visualizing the end of the race (even though the race is only two minutes long):

> ...when I'm starting to like get, cause like my first 50 of the race it’s so clear and I have it perfect, but like, I start to get like bored within the, I mean it’s only a two minute thing but, I don't know, more toward the end [it gets difficult], I guess trying to pull in different things like the noise and the smell and stuff like that. I kind of ignore that part sometimes.

P07 also reports that often times her body (specifically, her eyes) will react to her mental visualization:

> ...my eyes move a lot. I mean, sometimes it actually bothers me and I have to stop because of that, because I do it with eyes closed and sometimes if I get really into it I can feel my heart getting a little bit faster...

P07 acknowledged that she obtained her best time in swimming when she was consistently doing visualization. She stated that there is a direct relationship between her performance and her visualization practice. She acknowledged that it took some time to see an effect of the visualization exercises on performance, but that it did eventually make her better:

> I haven't done my best time for like two years and that was when I was doing the visualization like every night too, really, really well. And then I stopped doing it and I didn't go near the times anymore cause I like didn't, like, I just wasn't focusing I guess and um, in December, I started doing it again, cause my coach was like, "You know you should really try picking it up again" and I like talked to one of the sports psychologists and he was like, and we have meetings and they kind of point us in the right direction, and so I started doing it again, and like...I haven't been going my best time again, but I've been going consistently, like, in getting faster at each meet.

P07 said that it took her about a month "to get to the point where you feel like you are getting something out of it." She stated that she had to become totally consumed by the visualization for it to be effective:

> You need to have, like you can't have anything else going on. But like I do try to put a TV on or something because if I am at a meet, you're not going to be sitting in total silence. So I try to have stuff keep me, in the background, that I have to work on blocking out but um, it's hard to get that focus I guess.

Given her experience with this visualization exercise, I asked P07 to walk through her swimming visualization and talk it aloud:

> So I bend over and they say, "Take your marks." And then they start and then I dive in and I hit the water perfectly. And then, I have four really quick kicks up to the surface and then I break the surface and I feel-like I kind of think about how I'm going to feel—and I feel um, I'm not breathing and I can catch the water in front of me really easily and I feel really fast. And I can see the wall coming up and I grab it and then I turn off really quick and kick underwater really fast for a long time. And then I like, I can count in my head—I have never thought—I can be like "one, two, three, four, five," in the rhythm that I want to do it when I am swimming. And I come up with my head down and take a stroke and then I like take three strokes with my head up. But when I am doing it in my head, I'm not

> saying like "Take three strokes." It's more like I can think like, my head is up, I'm going one...two...three... like in the rhythm that I know my stroke is like. And, um, I'm kind of picturing where my, like—when I stroke, the water level's right here—and I am kind of picturing like that and then like then I can see the wall and there's a black line and line on the pool and I try to be like perfect with that. And I'm turning. There's eight laps so each lap is like that, but I try to think of like, put my race strategy in there. So like the first 50 I'll be like this, and the next 50 I feel like, um, "Keep the rhythm," and like, and "Keep it strong and long," and then the third 50 I try to, I—in my head I have like little key words and stuff, it's stupid but—the third 50 I'm like "Kick it into gear!" and I'm like kicking really—because I want to pick up the pace in that 50. And the last 50, it's hard because you know you're going to be hurting. So I try to imagine it's hurting but I don't care and I'm trying to go all out and I don't know, powering into the finish. And I can picture there's flags and sometimes you can catch it in your view and you can put your head down and hit the wall. There's so much like going on in my head. It's hard to describe it.

She acknowledged to me, as her description shows, that her swimming visualization was more than just mental imagery. It was visualizing the entire experience. Moreover, P07 said that it was more difficult to visualize at certain times than at others. She admitted:

> Like even if I'm stressed out in school or anything, like, just to sit down and take the time. I get really, you really need to relax yourself at first...but the more I do it, the easier, it definitely gets a lot easier and if I am consistent like, I get a lot better at it and it's easier to find that like zone, I guess.

While swimming was her primary focus, in her schoolwork P07 reported that she enjoyed English, but disliked Latin. She also noted that in math, she would do her best to follow systematic processes but would get frustrated when she could not figure it out. Her favorite course was art. She said:

> ...my art teacher in high school was really, well I had her in junior high then she came to the high school like two years later and um, she was really like open and like let me do whatever I wanted as far as art-wise and she introduced me to a lot of different media and stuff... I didn't know about perspective and all that kind of stuff. That concept she basically taught it to me. I didn't learn it through any other classes...

Reflecting on her own spatial ability, P07 thought she was average but she had never thought about thinking spatially. She said:

> Um, I can draw well and I can like picture how to draw things, but I definitely think I have problems with it sometimes. But like after, but if I spend the time with it I can usually figure it out.... I think I'm average...I don't think I've ever really thought about that. I mean in my art classes, they force you to think, "Picture this in your head," but I can't remember a specific moment where I was like, "Oh wow! I am picturing this."

4.3.5.2. Participant 7 Structural Description

P07's childhood experiences included playing with action figures and working with craft items, such as beads or ceramics. Through her school age years, her primary focus was swimming. P07 had extensive experience with spatial ability as it related to swimming visualization; the goal of which was improving performance. She acknowledged that when she visualized her performance, her mental imagery was vivid and often her body would react to what she was visualizing. In addition, stress affected how well she could visualize. She highlighted, however, that swimming visualization included not only the visual imagery but also the sounds, smells, and feelings as well. She stated that she was average in spatial ability due to some of the difficulties she had in the course exercises.

4.3.5.3. Participant 8 Textual Description

P08 stated that a large portion of his childhood activity was board games and video games. His favorite game was chess. He also reported playing with blocks as a child. I asked if he used pictures to build things from blocks and he responded:

> Not pictures, some, I don't have pictures, maybe if I see somebody else making something, I might try to make it like them. Otherwise, I would just make things that look good.

P08 said that a favorite past time was working on his aquarium and doing aquascaping. He said:

> Like back home, I made different kinds aquarium, aquascaping. Tried different things out. Designed different things for aquarium.

P08 said he did not enjoy school as he was growing up, nor did he particularly enjoy the courses he was taking at Purdue. He stated:

> Actually, I didn't like most of the courses. Ah, if I had to think one, I would say math or physics...Here, too, ah, I don't really enjoy a lot. If I where to pick, I would pick physics.

He said he enjoyed physics because, "It's like a puzzle sometimes; it can be like a game sometimes." P08 said when he solved physics problems he would often try to solve it mentally. If he had difficulty, he would try to help himself visualize by drawing a sketch. His least favorite courses were those that required memorization, such as social studies. He added:

> It’s uninteresting, but it becomes difficult because it is uninteresting. Like physics, it may be more difficult, but because you find it more interesting you are able to, what do you say, study it, or find a way to deal with it.

P08 reported that he thought he was average or a little above average in spatial ability. He acknowledged when he first became aware of his spatial ability:

> When I was in grade 12 in high school, I read about spatial ability when I took an IQ test.

4.3.5.4. Participant 8 Structural Description

P08 is a non-native English speaker; P08’s descriptions were very short and sometimes broken, making it difficult to elicit meaning. Nevertheless, he seemed uninterested in most school subjects except for physics. Most of his childhood experiences were focused on games or video games, his favorite being chess. He stated that he thought he was average or above average in spatial ability.

4.3.5.5. Participant 9 Textual Description

P09 acknowledged early experience with hands-on toys and outdoor activities. She said:

> I played with Legos a lot when I was little cause I had a younger brother...mom and dad always pushed me to play with him and get excited in, other things too. So, um, played with Legos, played outside a lot. I wasn't really into the whole Barbies and girly stuff when I was little. Played a lot of sports and games outside things like that.

P09 stated that she had a computer by the time she was six years-old and would often play games on it. She also had a Nintendo, so she "grew up playing video games and that sort of thing too." The outdoor activities that P09 referred to were predominately composed of riding bicycles, playing soccer, and jumping rope.

When P09 was young, she recounted having an active imagination. She said:

> I think I had a pretty active imagination. My mom always tells me that I would just come up with stories out of nowhere. Make up games to play, and that kind of things. So it’s probably really creative.

Her imagination would extend into making things out of boxes and paper towel tubes also. She remembered:

> I always enjoyed making odd stuff out of everyday objects. One time I took a shoebox and like made a mask or something out of it. I used a toilet paper roll for the nose or something and then painted it and all that kind of thing. My mom was like, "What’d you do?" I said, "I don't know." "Just clean it up," [she said].

P09 described herself as not being actively involved in hands-on activities growing up. She admitted:

> I always helped my dad out when he'd like change the oil or mess with the car, but I was just watching. I wasn't really hands-on, doing anything I suppose.

P09 grew up in a small high school, which made it easy to get to know everyone and made the teachers more approachable. She said that math, history, and English were her favorite subjects:

> I always enjoyed math, ah, I was always good at math and I always enjoyed it. I had really good teachers for math in high school, so, um, I think that had a lot to do with it. And I really enjoyed history. Physics was fun in high school, but I don't know about college cause I haven't started it yet so, but I keep hearing that it’s not so much fun any more, but I really enjoyed it then. And, I don't know. I haven't always been science oriented. I have always been good at English and history and math. That's pretty much it.

P09 acknowledged that it is important for her to be able to see a practical application of what she is learning. She mentioned:

> I took three years of biology in high school. By the time the second year came around, I was like, "I don't like this class anymore because um, it just seems more, ah," I don't know exactly what I am looking for. It was always, it just seemed like busy work to me. It didn't seem like something that I was going to practically use when I got out of high school. So I didn't, really like, math? You’re always going to need math. You’re always going to use that. It’s practical. English? You have to learn English to be able to communicate. I don't know. I guess history, I enjoyed history cause it’s where you come from. It’s always, um, interesting, and then, like I just did fine. I mean, I know biology is important, but I just didn't find it practical for what I wanted to do.

At the time of the study, P09’s favorite course at Purdue was Italian. She acknowledged that CGT had been difficult for her:

> I'm not having to work at it [Italian] as hard as I am in CGT, like, I don’t know. I don't know why I am having such a hard time. It just, it’s harder to visualize things. CS programming kind of makes...[more sense].

P09 reported that she thought she was low in spatial ability. While she has noticed an improvement due to the course, she still feels like she had a long way to go:

> I would have to say it's probably on the lower end. It's like, it's not lowest [her spatial ability], but it's not average either. It's probably in between. I'm thinking, I think it definitely could get better. I have definitely noticed an improvement since the first week of class. Like the first sketches, I was like, "What is going on?" I had no idea what was going on. "Ok. Let's sit down and try and figure out what's going on so." Um, spent some time with some of my friends who are also in the class and they are trying to explain it to me and I'm like, "Ok. So now I am going to go ponder this by myself and see if I can figure it out."

P09 acknowledged that she would often use physical objects to try to help her visualize:

> Like, I'd take like figures in my room and like sit it in front of me and turn it to the side and look at the right side and then, you know, and then look at the top and try to figure out how exactly we were transcribing what this is to paper and then how they like get it into the isometric views. Like I'm not really good with terminology either. So, like try and take objects and turn them around and figure out what they are going to look like.

P09 acknowledged that this course was the first time she had used her spatial ability in this way and she did get frustrated with not being able to visualize. P09 noted that often times she would also use her hands to try to help herself visualize problems.

4.3.5.6. Participant 9 Structural Description

P09 acknowledged childhood experiences playing with Legos, and outdoor and imaginative activities. Yet, she admitted that she was not really into hands-on activities growing up. In school, she found that she liked math, history, and English, subjects in which she could see long-term, practical application. She stated that her CGT course had been very difficult for her. She believed she was low in spatial ability and often had to put in more effort to understand it.

4.3.5.7. Participant 10 Textual Description

P10 described his childhood activities by emphasizing his use of Legos:

> Well I was always a big fan of Legos, and, and K'Nex. Anything you could just build stuff with. I've always enjoyed that kind of stuff, working with my hands. Just, you know, playing around with stuff like that. That was, yeah those were my favorite things as kids.

P10 recalled play activities with his twin brother, where they would do imaginative types of play also:

> ...my twin brother and I we would always do sounds, and would pretend we had superpowers and, you know, sword fight with whatever. Plastic swords, sticks, whatever we had at the moment. Stuff like that.

He also remembered doing many cardboard construction-type things and building model rockets:

> Anytime we got a chance to, you know, had an extra egg carton, paper towel tube, good wrapping paper cylinder, I would always try to make something out of it... I built model rockets, little ah...my cousin used to do it a lot and I'm like, "K, that's kind of cool, kind of neat." So we helped him, my twin brother and I helped him build one. One day then I'm like, "Hey, maybe this is something I'd like to do?" So, I started asking for them as gifts and what not. And I'd get them, build them, paint them, launch them. I always enjoyed that.

In sixth grade, P10 started playing the tuba, and eventually played three different brass instruments. He said he found them easy to learn, versus learning the recorder in fifth grade:

> The other instruments I actually found easier than the recorder because they only got three buttons, or valves. I just, I was never coordinated enough to get all the finger work in on the recorder. If I was ever going to do anything fancy with it.

In high school, P10 went on to orchestra and learned to play the string bass. He recalled what it was like to learn it:

> Reading the music came pretty naturally, but I had to get used to using my left hand, ah, to play, cause you know tuba and baritone and everything else I've been playing with my right hand. My left hand had to get coordinated enough to get some, you know, the complicated note patterns and rhythms and what not.

While he did not have any particular mechanical hobbies, P10 did say he would call himself a "tinkerer." He said, "If something was broken I would pretty much take it apart and fix it before I threw it away."

In high school, P10 said that his favorite courses were physics and kinetics, because they described how things work. He commented:

> I liked physics in high school. It was just a good class, you know. Kinetics, see how things work and just...and physics. I like it because it’s set laws you will have to follow and there’s no other way it will work. Chemistry, I didn't like so much because it had too many variables.

Regarding his spatial ability, P10 acknowledged that he needed to work on it. He admitted:

> I would say I need work. Um, as far as this CGT course goes, I can, when they have a part that I need to sketch out I can visualize the part, but I can't get it down on paper if I need to sketch it.

While he initially addressed the fact that he was not skilled at drawing, later he commented that he needed to work on both sketching and visualization skills. He said, "It might be a little bit of both" that he needed to improve. The CGT course was actually the first time he had exercised his spatial ability. He noted frustration with the MRT exam:

> ...on that the test we did, the spatial ability test. That was, that was kind of frustrating. Cause one, we’re on a time limit and two, I'm trying to sit there thinking, "If you move that there and twist this around," and just sitting there kind of thinking, that it's a little frustrating. I think if I look at it long enough, I'll be ok, but with the time limit, it was kind of frustrating.

4.3.5.8. Participant 10 Structural Description

P10’s childhood experiences included construction toys such as Legos and K’Nex, imaginative play, and cardboard-type construction activities. As he grew older, he was involved in music and found that playing brass instruments came quite easily. In school, practical subjects such as physics and kinetics interested him because they showed how the world worked. He was aware that his own spatial ability and drawing skills needed to improve. The MRT frustrated him somewhat.

4.3.5.9. Participant 11 Textual Description

P11 acknowledged childhood interest in sports and outdoor activities. He said:

> If not outside then I know inside I played. Also, I played with cars and trucks. Um, I had...mostly just the vehicles. Um, I did have a little farm set, you know with the barn and stuff. Also had little Brio train sets...

He said for a while, he also had an interest in K’Nex, but that he lost interest in playing with them. As he got older, P11 did not have a computer, but did report playing many sports-based video games. He also built model train sets for five years through involvement with 4H.

In school, P11’s favorite courses were history, geography, and social studies. He said, "...it was, [it] just came easy." His least favorite course was English. He admitted that grammar, specifically sentence construction, was problematic for him. Additionally, he added that, while he understands mathematical rules, calculus and some other areas have made math difficult for him.

P11 said that he thought he was average or below average in spatial ability. Using the MRT as a reference, he said, "some [of the problems] I could visualize, and thought I was pretty sure of what it was and some I wasn't really sure which one was which." P11 acknowledged that he found the sketching exercises in CGT 163 difficult. He believed this was a combination of sketching and visualization difficulty.

4.3.5.10. Participant 11 Structural Description

P11's primary childhood activities were centered on sports and being outdoors. He had access to toys such as K'Nex, but quickly lost interest in them. In school, his favorite courses were history, geography, and social studies because they were easy for him, whereas English and math were more difficult. P11 believed he was average or below average in spatial ability.

4.3.5.11. Participant 12 Textual Description

P12 reports that she often played with "guy toys." She would often use Legos with her father, as opposed to Barbies with her sister. She remembered:

> My dad and I would just build stuff out of our imagination. We would just like put blocks here...pile them up just to see how high we could get them. It was always fun just knocking them down. And starting over again. But, Legos, Legos were just a thing we kind of played with, just kind of build our own stuff. We didn't have like the fancy ones they have now were you are set on building one thing. So we just kind of like build and stuck them together.

P12 also stated that she played on the computer and played video games a lot. She said computer-learning games, such as MathHeads and Carmen Sandiego, were ones she played a lot:

> I think we actually like crashed the CD because we played it so much. Because it kind of broke our computer after a while. It wouldn't start. Um, I loved mystery games like um, there was one that was a math one where you are like in a haunted house and you have to like add stuff to get points to get out of the house and stuff. I just, I remember playing lots of games like that.

P12 also remembered doing puzzles with her father quite often.

As she thought about her childhood, P12 reported that she was a very active child, with an equally active imagination:

> I had a pretty active imagination. I was always going off on something. Just building or exploring or playing on the computer games. Just kind of, I didn't like to sit. I was very AD. I swear I had ADHD. I mean, bouncing off the walls all the time. Just, I could never sit still so I was always doing something.

Yet, P12 acknowledged one activity that managed to hold her attention, playing the harp:

> Know how I said, I can never really sit down and stay still? This is the one thing that like, I could do and it's just, I can pick up stuff pretty easily now and I had fun with it when I was little. I watched, *I Love Lucy* was our favorite show and there was this one episode where Harpo Marx came to play *Take Me Out to the Ballgame* and that night my parents said that I came into their room and said that I wanted to start playing. And I, I guess I kept persuading them for a year. They started me when I was in kindergarten.

P12 continued to play the harp through high school and in college. She developed skill on it and became very good at sight-reading music. When she viewed a new piece of music, she said:

> I could hear the notes [in her head], but rhythm was hard for me, cause ah, I didn't have a good rhythm background so like I would always, um, playing how I thought it would be and sometimes that was hard because this is how I thought it would be but music says no, and my teacher, and they would get on me a lot about that. Cause I usually like to go faster. When, this is supposed to be a little slow and elegant um, but besides like sight-reading and the notes, I was pretty good at that.

I asked P12 if she had any mechanical hobbies growing up. She remembered a story about herself regarding "being mechanically inclined":

> ...my mom came home one day and I was under the sink and I had taken the sink apart cause I had dropped an earring or a ring down it and I wanted to get it out. So, I had like the pipes everywhere and I got my ring and I put it back together, so I would, if there was a problem in the house,

> mom would come to me and I might not have always known what I was doing but like I had fun taking things apart...sometimes I couldn't put it back together quite the same way, but ah, the sinks was definitely one I would do...I did all the sinks in the house, that was fun.

After hearing this story, I asked P12 if she would call herself a "tinkerer." She responded:

> Yeah, I'm not always the best at putting it back together, but I do like taking stuff apart. And just like seeing what's in there. Oh, I built my own computer, once. Um, so that was fun I could actually got to see plugging everything in to the computer, um. I had a little help, but that was fun. Cause I liked seeing everything and I built it so I could see the inside of it. Um, but I didn't really touch that once it was broken cause I really wasn't quite sure what it was doing!

P12 acknowledged that science and math were subjects that she picked up easily, whereas reading was quite difficult. She said:

> I always loved math and science. They're just, I wouldn't say I love it, it came easier for me. And so I liked it because I did well in it. Um, I hate reading. I, my mom and I would fight all the time for summer reading or for books for school, cause I would never read. It's just, maybe it’s, partly cause I just hate the books they picked out. I am very picky but, so I like to read history. I enjoy history. I think history is very interesting. Um, some of it can be boring, but, I can, I love stuff on, ah, WWII and [WW]I and the holocaust and the big wars that have happened. I really enjoy that, and I enjoy reading about it but...science, I hate chemistry.

P12 seemed unsure why math came more easily for her. She said:

> I don't know, exactly, cause I know, I don't know which parent of mine has very strong in math. So I was just kind of, I can understand the concepts maybe. All of it easier than some people, or maybe I just work at it a little more and I can understand it. Um, and obviously math gets harder as I'm going, so it gets more difficult and, I slack off, which is probably more of my result of like, if I do bad on a test I like, I, I find it fascinating how these scientists came up with these ideas. And I'm just kind of like, how in the world did they think of this?

I inquired if P12 thought she was strong in math because she thinks about it spatially. She replied:

> I wouldn't say I have a spatial concept of math. I'm pretty, I am pretty attached to my calculator. I mean those people who can multiply and divide in their heads, I think that is fascinating, but I can't do that at all. So, I've had a more like, I stick to the numbers and the rules. This is what I do, and once you have that set of rules, I can kind of do it that way, step-by-step. If I tried to not read the instructions and do it on my own, I usually get lost somewhere in there or mess something up.

P12 then admitted that she was extremely weak in spelling:

> I am the world's worst speller. I think they made spell check just for me. Um, I hate using, sometimes, sometimes I hate using the dictionary because I don't know how to spell it. So I like get to the first two letters and I don't know where to go. So I sometimes feel it's not helpful but, I can't spell. Grammar is very hard for me, to put sentences together. I have been tested for that and there is something with the coding in, ah, reading that I cannot do. I don't really know what the test said, but it's just like, I can read a passage and go back to it and I have no idea like what I just read. Like breaking down the words, I can't really, I just can't really connect everything, and my ah, papers that I write are kind of more, like grade school, but very, kind of chopped and not professional or at my level. So, I'm definitely like behind in my reading and grammar skills and stuff like that so, it's definitely a weakness.

She acknowledged that she compensated for her writing weakness in several ways. A technique new to her was the concept of a mental map. She said that it was a more natural way for her to organize her thoughts for writing tasks.

P12 acknowledged that she was involved in track in high school and college. She acknowledged using visualization for preparation:

> So I'd like always visualize and like, "Ok. I know what I am going to feel like when I get to this point. How am I going to get through it and push to the end?" And stuff like that, and my coach, um, won the men's decathlon in 88 for the U.S. Olympic Open. So he emphasized just visualizing and just staying calm, like I was never nervous before I ran. I was calm and I was just, "I know I'm good, I know what I can do. I don't care about these people. I'm going to run my race." And I could see it—running—and I could, I just remember that feeling I feel when I'm in the middle of my

> races, like before, I'm like, "Ok. Just get through it. You know what? You've done this a bazillion times before you know, know what's going to happen so," and I try to change it each time. I, I was very visual.

P12 said she visualized, but not in relation to time. Her focus was predominantly on how she would feel at various points in the race. P12 reported that often when she would visualize herself running, her body would actually have the sensation of pain or the sensation of actually running. She also told me that when she visualized running, she used both first and third person views.

P12 admitted that it was her second time to take CGT 163. She reported that she is weaker in creating pictorial drawings. She had little trouble in the creation of multiview drawings from 3D objects. However, she thought that the MRT test was fun. She found herself using her hands and turning the paper to help her visualize.

P12 reported that when she got frustrated, she had to put the problem down and come back to it later. She stated that this was a common approach for her when she was stuck on a problem, regardless of the course. She said:

> Sometimes, I just kind a have to set it down, and come back to it. Because, when, I am the kind of person when I get flustered and frustrated, I pretty much set up a mental, like I can’t do anything else and I have to go, like take a shower or watch TV for an hour and just kind of like calm down and just like relax and then try to tackle it again. I pretty much do that with all my subjects. I am the kind of person that if I see a bunch of givens for like a, given information about a problem, sometimes I have, when I see a lot of information, I can't break it down, to like only need this and this, this I don't need, what I am trying to find. I get very flustered easily so, but this class in particular, since we have a week to do the assignments, if I start it earlier, I'll just put it away and if I come back to it and still have a question then I like, might ask a friend, or my TA. It depends, maybe just give me another perspective, and usually, "Oh. Ok, that makes sense" and then I can do it. But, so it’s just kind of set it down for a while or a day or something.

4.3.5.12. Participant 12 Structural Description

P12's childhood experiences included playing with Legos, playing computer learning games, and imaginative activities. She was a very active child. Many of the things she did were hands-on and interactive. In school, she was strong in math and science and weak in English. She acknowledged that she did have some difficulties in spatial ability, but a greater issue for her was getting frustrated with the material. She admitted that if she got frustrated, she had to set the problem aside and come back to it later.

4.3.6. First Interview Summary

The analysis of the first interview revealed a tremendous amount of variety in the background of the participants. Once the first interview analysis was complete, I began seeing some characteristics emerge, both within and across groups of individuals.

For example, high visualization students and low visualization students both expressed interest or access to hands-on toys such as Legos. However, the frequency and depth with which the high visualizers communicated that these toys occupied their time was greater than low visualizers were. Similarly, high visualizers more often reported that math was a favorite subject and none said that math was their least favorite course. While a "sense of similarities and differences" began to emerge, I hesitated in making sole determinations based on this single data source. To provide a sense for the experiences of the entire group, Table 4.3 shows the frequency of various experiences mentioned by each of the participants.

Table 4.3.

The Frequencies of Various Background Experiences Mentioned by the Participants.

High Visualizer Frequency	Activity	Low Visualizer Frequency
2	"Tinkering"	2
1	Academic Competitions	0
0	Aquarium	1
0	Action Figures	1
2	Barbies	0
1	Blocks	1
0	Board games	1
0	Cars/Trucks	1
1	Computer Activities	2
3	Craft Hobbies	3
5	Legos/K'Nex	3
1	Mechanics	0
1	Model Building	0
1	Outdoor Activities	2
1	Play-Doh/Clay	1
5	Playing a Musical Instrument	3
2	Puzzles (2D or 3D)	1
4	Sports	3
1	Theatre	1
4	Video Games	4
2	Woodworking, Carpentry or Construction	0

The participants acknowledged myriad subjects and courses as their favorite and least favorite (some acknowledging more than one). Table 4.4 shows the frequency of these. Note that not all high ability students acknowledged a least favorite course.

Table 4.4.

The Frequencies of Favorite and Least Favorite Subjects Mentioned by the Participants.

	Favorite Courses	
High Visualizers	Subject	Low Visualizer
2	Art	0
0	English	2
6	Math	2
2	Science	2
1	Social Studies	3
	Least Favorite Courses	
High Visualizers	Subject	Low Visualizers
1	Art/Drawing	0
1	English/Reading/Spelling	2
0	Latin	1
0	Math	2

In addition to these background factors, it was intriguing to notice that high visualizers had a tendency (1) to be more conservative in their estimation of their own spatial ability, (2) to be more cognizant of their learning needs (several mentioned needing applied or analytical examples), and (3) to report using a feature-based comparison approach on the MRT exam to determine the correct answers.

Other noteworthy elements that emerged related to participant feelings toward spatial tasks. While none of the questions in the first interview were aimed at student feelings, high visualizers were more apt to exude or communicate confidence (as one might expect), but they were also more apt to acknowledge frustration and the effect of stress on their ability to visualize. A dichotomy appeared within high visualizers that I did not expect. While they were confident in their abilities, they were also apt to experience frustration (at least initially) and allow stress (related to the problem or life in general) to affect their ability to focus or concentrate on the assignments or tasks they needed to complete.

A final thread of conversation that several of the participants mentioned was the use of visualization to improve in sports. It was evident from the detailed descriptions from P01, P06, P07, and P12 that, regardless of their spatial ability grouping in the study, they had extensive experience using spatial ability for sports visualization—often going beyond the spatial sense to include smell, sound, and feeling. It was intriguing that they had psychological training in this. I wondered if visualization skill in sports might transfer; helping them in course assignments that required visualization. Data collected later in the study would contradict this notion.

Again, bearing in mind that the first interview was only a single data source, these initial threads seemed to emerge from the data. As I began analyzing the second interview, I was interested whether these threads would emerge in subsequent data sources as well. Curiosity made me wonder what new threads might emerge from the applied tasks executed in the second interview also.

4.4. Data from the Second Interview

As discussed in Chapter 3, the second interview required that the participants do applied problems using a think aloud procedure, attempting to elicit thoughts, feelings, approach, and processes. Additionally, the second interview included some questions relative to the applied tasks.

The data from the second interview were from three sources. The first data were the themes that emerged from the transcript of the participant’s think aloud procedure. The second data were observation notes that I took during the session and the third data were the solutions generated by the participant (which were analyzed as well). Table 4.5 shows the order of the second interviews with the participants

Table 4.5.

The Order of the Participants in Interview 2.

Order	Participant	Order	Participant	Order	Participant
1	P04	5	P01	9	P07
2	P05	6	P02	10	P12
3	P10	7	P09	11	P08
4	P03	8	P11	12	P06

This section begins with a discussion of a change that was made to the participant tasks to accommodate participants that were unable to complete the second and third problems. It then presents the third epoché session in which I did the same tasks as the participants, using the same procedure. Following this is the course instructor’s execution of the same, followed by data from each participant. It should be noted that due to a recording error, P04’s think aloud data was lost. Nevertheless, her solutions and relative observation notes will be discussed.

4.4.1. Modification of Tasks

Within the first of the second interviews, it became apparent that I needed to have more simplistic objects prepared in the event that the participant could not complete the second problem (which was one of two that required the creation of an isometric pictorial). It was highly likely that a participant not able solve the second problem would not be able to solve the third problem either. Rather than stop the interview entirely, it seemed appropriate to present the participant with a simpler problem and gather data from it.

After the first interview, which was with P04, I created three alternative problems. These alternatives were actually parts extracted from the second problem. Figure 4.1 shows the original problem and Figure 4.2 shows the three alternatives. The alternative problem given to the participant was based on where they started on the second problem. For example, if they started on the top of the object, alternative A was given. If they started on the front of the object, alternative B was given. Due to the complexity of the right-hand end, which included a compound angle, no participant started there. Therefore, alternative C was never used.

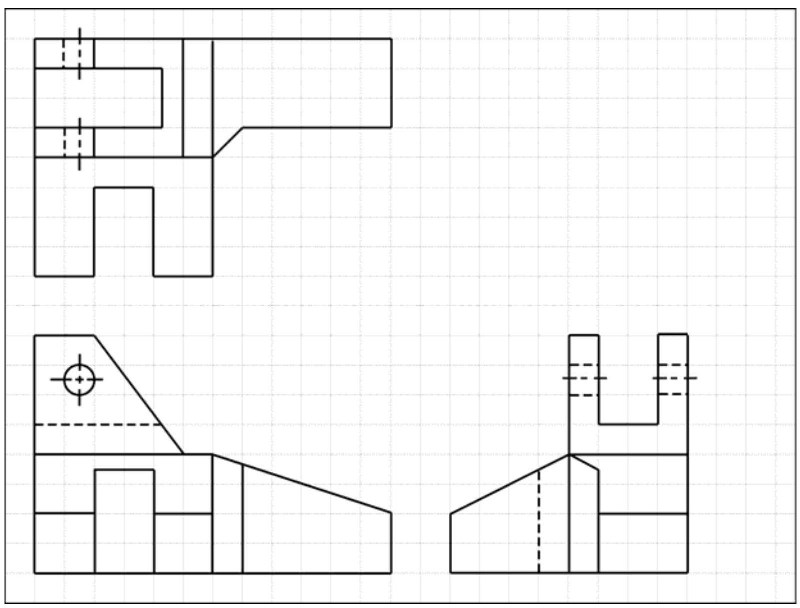

Figure 4.1. The second problem given to the students required that an isometric pictorial be developed from the given multiviews.

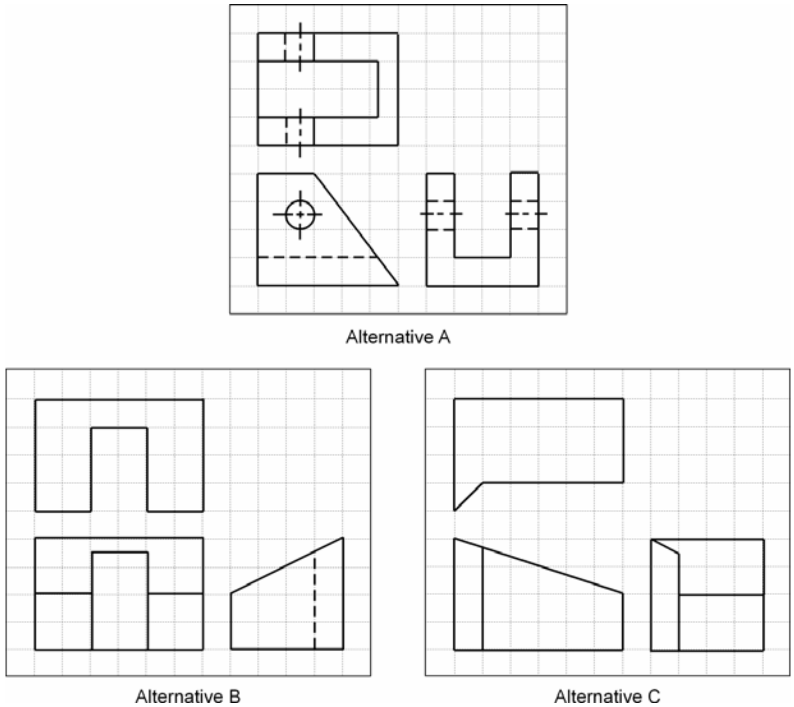

Figure 4.2. The three alternatives were actually extracted parts of the original second problem. Alternative A is the top, alternative B is the front (or left end in the pictorial), and alternative C is the right-hand end of the object.

In addition to creating alternative problems, I also decided to make the interview somewhat instructional, based upon difficulties that the participant had. I told all participants that at the end of the interview I would provide them feedback on how they had done on the problems as well as recommendations (procedural or otherwise) that would help them solve spatial problems. It was actually due to this decision that one of the major findings of this study emerged. These instructional sessions led to the emergence of a process for the development of pictorial drawings, discussed in the next chapter (see section 5.1.4.4). It should be noted that all of the low ability participants were provided instruction on the creation of pictorial drawings from multiviews. The high ability participants were only given instruction on centering pictorial drawings on the sketch paper; none was provided instruction on the pictorial drawing process itself.

4.4.2. Researcher Epoché from the Second Interview

To begin the epoché session, I addressed the question pertaining to how I felt about spatial problems:

> Concerning the pre-problem questions, how do I feel about applied problems? I guess it doesn't, putting myself as if I didn't know what the questions were...it wouldn't necessarily bother me. I am very comfortable using my spatial ability. It is not very often that I can't visualize a problem or have difficulty with it, so I don't necessarily feel apprehensive or trouble about doing spatial problems. I don't think I will have any problems with any of the questions.

4.4.2.1. Researcher: Problem 1

The process I used to solve the first problem was modeled after what was presented in CGT 163. I began reviewing the given isometric to imagine the overall views quickly, looking for parts that would be difficult. At the same time, I tried to figure out which view should be the front view (that is, which is the most descriptive view of the object):

> Concerning the first problem as I take a look at I know the goal here is to draw multiviews. Immediately when I am posed with a problem like this I guess immediately I start to think ok, which view is going to be the front, which is the most descriptive view.
>
> In this case it looks like it is from the left given this pictorial drawing...And so, in drawings like this I typically think about what's going to be the front view, what's going to be the right side view and all that...In this particular one I don't necessarily see anything that is particularly challenging....I see that there is an oblique surface.
>
> I guess the next thing I'd typically do, aside from thinking about views, is I think about what kinds of surfaces are in the object whether there's...whether they're predominantly normal surfaces, whether there's angled surfaces, whether they’re inclined or whether. There are oblique surfaces as I look at this. I see one inclined surface, one oblique surface...um, typically when I see oblique surfaces it jogs my memory to make sure when I am drawing the views to kind a pay special attention because oblique views can be somewhat troublesome when you start drawing.

To begin the drawing, I boxed in the front view and drew the positive geometry in the front view, then proceeded to do the same with the right side and top views, respectively. Once the positive geometry was completed, I stopped to review what I had done:

> And, so now I think I've got all the positive geometry. Just checking across views comparing it to the orthographic view to be sure I've got all the all the stuff in there. I guess at this point I'll deal with the negative geometry. I think I've got all the positive geometry then I'll do the negative geometry. I guess I'll start with he hole that appears in the top view then I'll find it's center.

Once I had drawn all the negative geometry, I again reviewed the drawing:

> There. I think these are completed, I 'm just now looking across the views comparing it to the pictorial. Make sure I got all my lines and everything. Ok.

Figure 4.3 shows the solution created for problem 1. I made one error, which was misalignment of the holes in the top and front views.

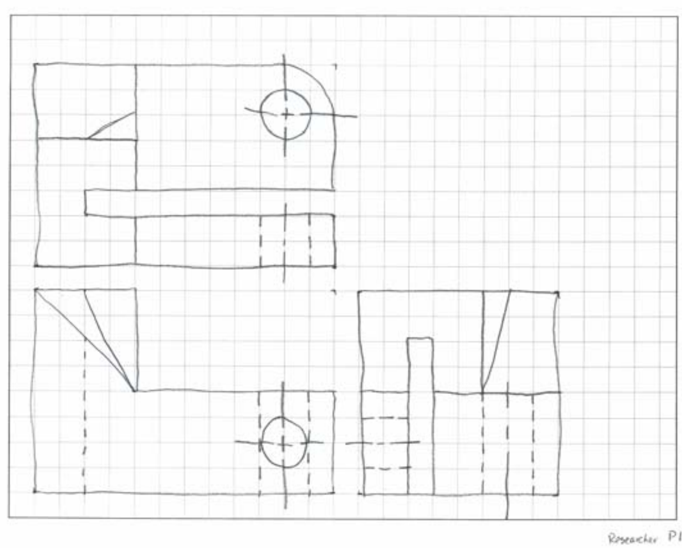

Figure 4.3. My solution to problem 1 had one error in the top and front views.

4.4.2.2. Researcher: Problem 2

As I began the second problem, I acknowledged trying to picture the object in my mind, and then how I would approach starting the drawing:

> So as I start to look at this object I, um, I guess what I start doing is when I, I need to draw 3D pictorials I look at, I am looking across the views to try to picture in my mind, what the object looks like.
>
> I am noticing at the top, on the top there's like this, um, like upside down C that looks like it has an angled surface um, I am looking at the top view predominantly to get the overall shape of the object because it looks like in the front view you can see several angled front and right surfaces. Actually you see three angled surfaces so I am using the top view predominantly to kind of orient myself to this object, because it has, I guess it has the most, I don’t' know, not really sure why I am looking at the top view, I'm using it predominantly.
>
> Um, to get an overall feel for the object then I am starting to get, pretty well got a picture of it in my mind and so I guess once, once now I can see it, um, I guess what I am going to do is thinking about how I am going to start drawing it. Um, I’ll probably begin by boxing it in since a major portion of the, when I look at the top view of it, a major portion of the lower right hand, which would be the front of the object is missing so I, I need a reference point out in the front. I guess I could start at the top of the object in the back and build forward. Um, but since 163 uses the box technique I'll go ahead and use a box technique.

As I talked through the object, I acknowledged beginning with the normal surfaces on the top and front sides. I think completed the top of the object and front of the object, saving the right-hand end (which contained the compound angle) for last. After completing the right-hand end, I went back and did the negative geometry. Figure 4.4 shows my solution, which did not have any errors.

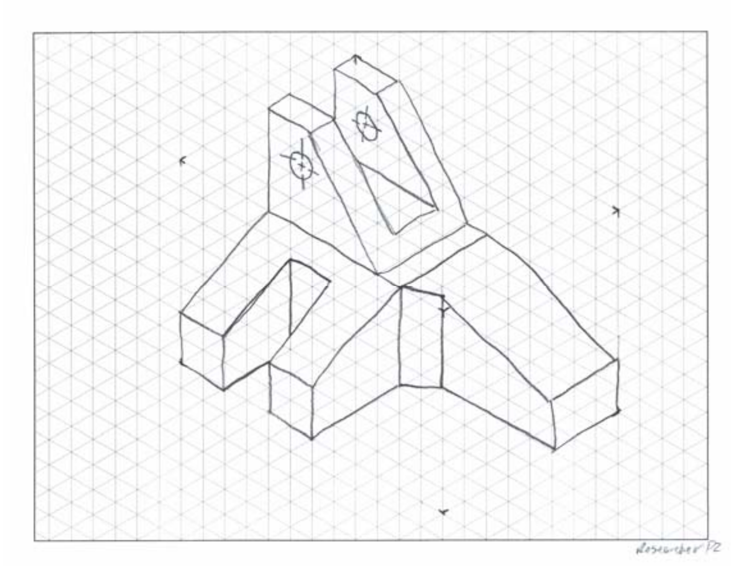

Figure 4.4. My solution to the second problem.

4.4.2.3. Researcher: Problem 3

To begin the third problem, again I stopped to visualize the object:

> OK. This is pretty complex. Um, again I don't know maybe it's, maybe it's, tendency, I'm looking at the top view, cause it looks like it's got relatively normal surfaces. I can see that there's an angled surface, actually several angled surfaces. As I look across the views, I'm trying to, trying to picture in my mind what this thing looks like um, this one's a little more difficult cause it has several hidden features. Ok I've got the picture in my mind now I'm trying to think about how I'm going to develop this as a pictorial. All right. So I kind of got it in my mind. All right. I got it.
>
> Um, so now I am thinking about how I am going to orient this. I am going to use the boxing technique again since, because that is what the students use in the class. Um, so I am going to pick a point lower, corner of the page over to the right some. And I am going to start boxing this in and...guess I'll do left to right or front to back first.

After drawing the box for the object, I started by putting in the normal surfaces (surfaces collinear with the ends of the box) in the top view, working from top down. I then worked on the left-hand end of the object, completed it, and worked on the right side. Once the positive geometry was drawn, I then focused on the negative geometry. Afterwards, I stopped to check my work:

> ...and think it's done. I am looking across the views now, make sure that everything is there. Yep, everything is done.

Figure 4.5 shows my solution to the third problem. No errors were made.

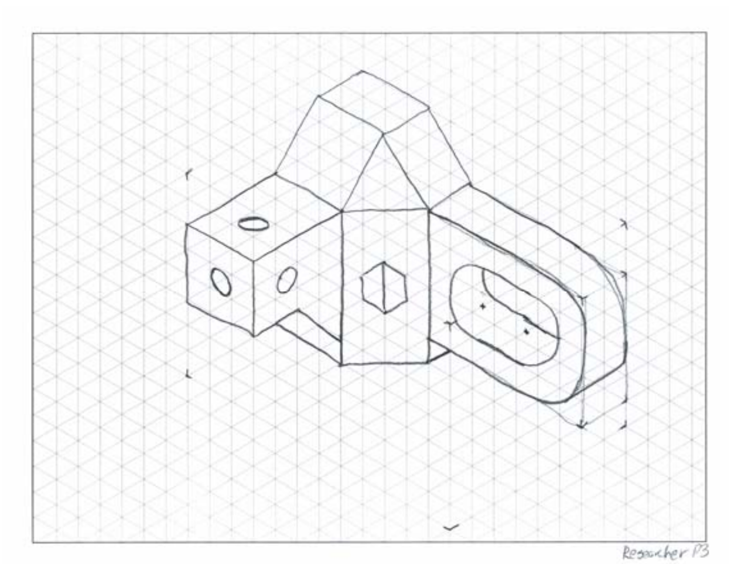

Figure 4.5. My solution to the third problem contained no errors.

4.4.2.4. <u>Researcher: Summative Questions</u>

Upon completing the three problems, I pondered the questions posed about the applied tasks:

> As I think about these three things I have just done the easier one, for me is probably, for me is working from...if I've got a 3D object and I have to draw the multiviews, I think that's easier. I guess because you can approach it from a...just thinking aloud, I think it's because you can approach it from a feature based, you can approach it feature by feature and you can kind a deal with the views. I mean you do get into when you're working across the views having to find where, you know, those angled slots where they end, that was kind of difficult. But generally

> speaking it’s easier to do multiview drawings from a 3D object than it is to visualize what the 3D object looks like, at least for me anyway.

4.4.3. Course Instructor’s Second Interview

As previously acknowledged, the course instructor participated in a single interview in which he was asked questions from the first and second interviews sequentially in one meeting. Because of this, the course instructor only did the first two problems from the second interview.

4.4.3.1. Course Instructor: Problem 1

When given the first problem the CI briefly looked at it and then started drawing. While he did not comment on the object, it is assumed that it did not take long for him to visualize the object. He began by drawing the construction boxed for all of the views. He then declared:

> I want to do the construction [boxes] first so that if I don't get anything else at least I know the overall size of it. Then I am going to go ahead and start to "featurize" this thing. I am going to look for all positive geometry first and I am going to try to do positive geometry in chunks. The first thing that I am going to do is what I consider the base of this thing...

He then began to draw the outer boundary of the object in all views and draw the positive features of the object by cutting or removing features in the view. Typically, he would draw a feature in one view and then complete that same feature in the remainder of the views. As he was drawing, the CI seemed verbalize his thoughts and actions very fluidly. Once he was done with the positive geometry, he completed the negative geometry.

Once he thought he was done, he stopped and reviewed his work, "I better take a look at this thing, drawing this thing like this, get myself in trouble. Just darkening in the lines now. I think that’s it." Figure 4.6 shows the CI’s solution, which contained no errors.

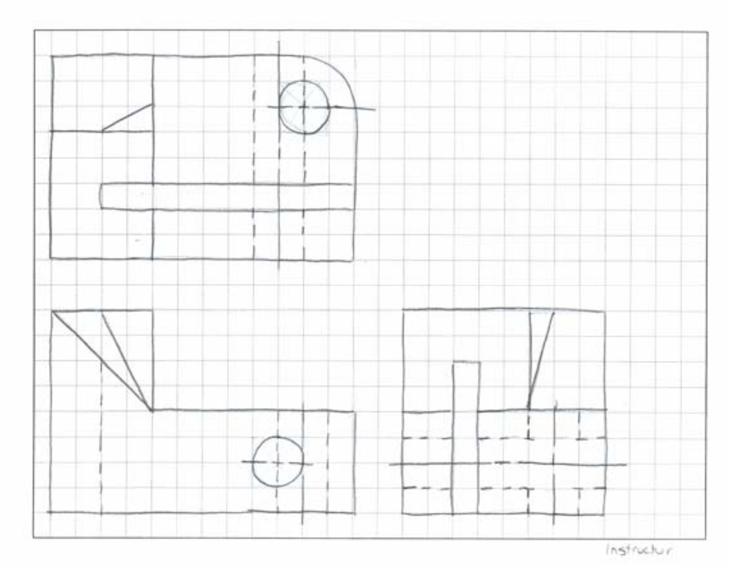

Figure 4.6. The CI's solution to problem 1 contained no errors.

4.4.3.2. Course Instructor: Problem 2

As he did with the first problem, the CI did not spend much time visualizing the object. He quickly began by creating an isometric box to contain the object. He said, "There it is. The volumetric prism, prism before it gets mutilated." This statement implied how he thought about the creation of the object—that he thought about cutting away pieces of the object, like a sculptor, to create the object. He continued:

> Um again I am going to take individual pieces of geometry and start just cutting stuff away. And I don't know if there is a method to the madness on this, but I will do like a feature at a time. So like I will look at this whole front area do, do this area in the front before I even think about anything behind it, because if I don't, I will ultimately skip something. I will forget about something.

The CI began by creating the front-left portion of the object. He then moved to the top of the object. He then dealt with the compound angle on the right end of the object. He acknowledged that the compound angle might be a feature that challenged him:

> And then I have to come through here, and you got this nasty cutout here. So this thing here goes straight back and you got a compound angle on here, you dog. Ok. So this thing goes straight back. Let me go ahead and put this part in here first so I can figure out what is going on. So it starts here, ok. And it's going to be on this surface, but it's back in 1. So one block here and then it's, let's see. Then it's one block here and this thing is [Counting] four, it comes up. I just got to stop here and think for a minute. So it's coming back in one, go to the outside, drive it over to here. This is where I may even screw this one up. So that goes from here...this is coming up. So these have got to be, this has got to be parallel. Ok this has got to come back here parallel. No matter what. And it's going to get to that point. Where is that point? That point is at the very top. It's one and three so I am on the very top. It's one over [Counting] 3. And then it's going to go down, till it hits that incline. So I am going to have to draw a line parallel here. And then on the top, we're over [Counting] three. [Counting] three. It's going to have to hit this line, it's going to have to hit this line. Got to find that rascal point. You may have me, Jamie. It's, up here. Over one. Forward three. Over one. One, two, three, maybe it's right here...that is it. Right there. Then it goes from there to there, there down to there. And there to there. There over to there. And there down to there. And the rest of that gets darkened in. And I think that's it.
>
> That's not easy.

After only a few minutes, the CI figured out the complex part of the second problem. As noted in the transcript above, completion of that feature of the object required him to procedurally and analytically figure out what was going on. Even though he could visualize it, sketching it required a systematic process. Figure 4.7 shows the CI's solution to the second problem, which had no errors.

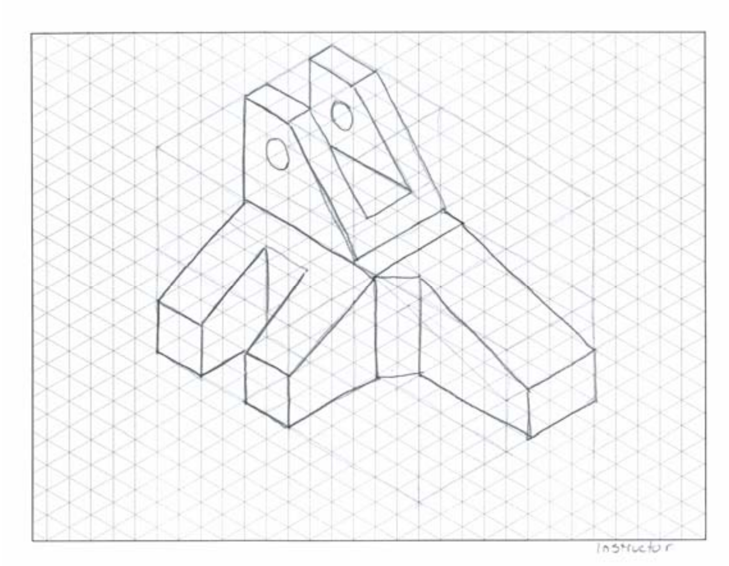

Figure 4.7. The CI's solution to the second problem had no errors.

4.4.4. Second Interview with the High Visualization Group

The following sections provide the textural and structural descriptions for each of the high visualization interviewees.

4.4.4.1. <u>Participant 01 Textural Description</u>

When asked, P01 related that she did not have much concern about doing applied problems in the second interview. She said that she was having little difficulty with the sketching assignments in the course, except for section and auxiliary views, which were initially a "weird concept" for her.

4.4.4.1.1. P01: Problem 1

P01 spent little time trying to visualize the first problem. She immediately started drawing the construction boxes for all of the views and then started creating the positive geometry in the front view. When she got to the oblique surface, she started labeling the points. She said:

> Now I just like to like draw points where these points all go...And then labeling these points with letters cause it’s a lot easier for me as Dr. Miller showed us in class.

She said that for any problem that has an oblique surface she uses the point labeling technique.

She continued the positive geometry through the top and right side views and then did the negative geometry. She stopped to check her work once in the middle. Once she had completed the views, however, she did not do a final review on her drawing, which is shown in Figure 4.8. As a result, her drawing had several errors that appeared to be due to rushing through the problem. A good example is the completion of the slot in the top view. My observation notes referred to this also. At the time, I wondered why she was in such a hurry, although I did not ask her. Her other two problems suffered from her rushing through as well. Additionally, compared to other high spatial ability participants, she was not very communicative in describing her thoughts as she worked.

4.4.4.1.2. P02: Problem 2

When presented with the second problem, P02 took some time to visualize the object. She said, "Right now I am just looking at it and trying to figure out what it looks like." Once she started drawing, she created an isometric box to contain the object. She verbalized what part of the object she was going to start with; she began with the top U-shape feature. She also was able pick a starting point on the grid paper that would accommodate the entire object.

Following the top U-shape, she then completed the front or left U-shape, saving the right end of the object for last. Once she got to the right end of the object, again she appeared to be rushing through the problem, as my observation notes reported. She left the problem in an incomplete state and said, "Ok." Figure 4.9 shows P01’s solution to problem 2, which had several missing lines and incorrect features.

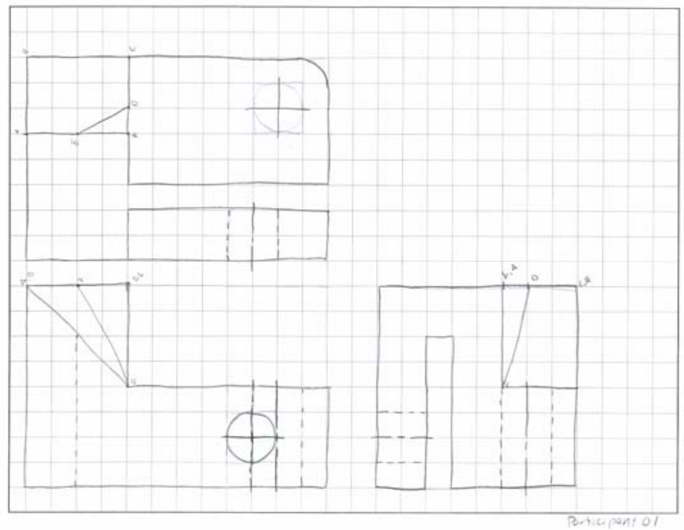

Figure 4.8. P01’s solution to problem 1 had several errors.

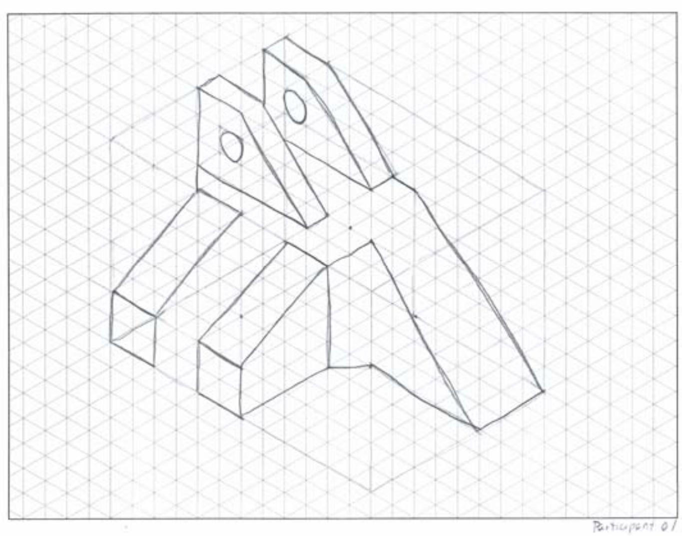

Figure 4.9. P01’s incomplete solution of problem 2.

4.4.4.1.3. P01: Problem 3

Although P01 took time to visualize the second object, she immediately started drawing the isometric box on the third problem. However, she had to start over because her box was in the wrong place.

She began drawing the right-hand end that contained a loop-feature but then found it difficult. She erased what she had drawn and started from the top of the object. She continued to work on problem 3, but eventually stopped and acknowledged that she knew it was not correct. She said she could mentally visualize it, but was unsure how to draw it. Figure 4.10 shows her incorrect solution.

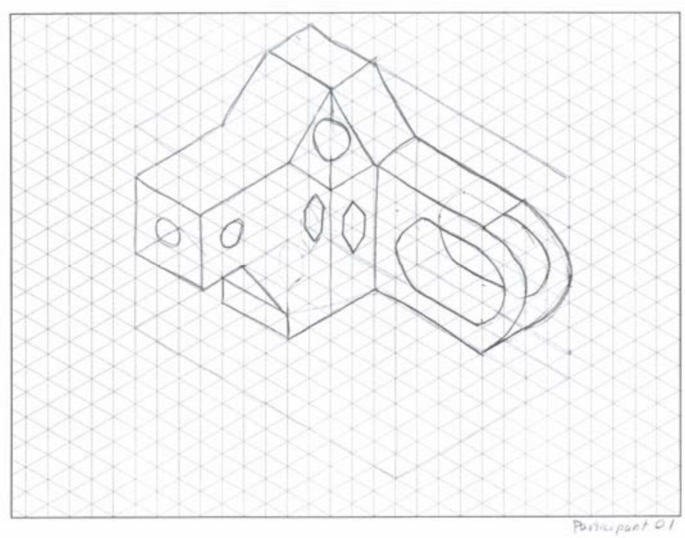

Figure 4.10. While parts of it were correct, P01's solution to the third problem was incorrect.

4.4.4.1.4. P01: Summative Questions

After completing the exercises, P01 said that she thought that problem 3 was the most difficult. She said that she thought it was easier to take the 3D and do the multiviews. When I asked her why, she said:

> I don't know. I think I can pick off, "Oh, there's that side. Oh, this is where these lines go." Other than like, this is like a little more difficult cause you have to look at them [multiviews] and try and like put it together in your head and what the shape is going to look like 3D, and then draw it in 3D.

At the end of the interview with P01, I provided her with some basic recommendations relative to making sure she did not forget to review her work to catch small errors and a process for the development of pictorial drawings (since she had difficulty with some details of both pictorials).

4.4.4.2. Participant 01 Structural Description

P01 seemed unconcerned about having to do sketching tasks in the second interview. While she seemed to rush through the exercises, leaving many of her solutions either incomplete or with errors, it seemed obvious that she could see the object and knew how to do both multiviews and pictorials. She acknowledged that she thought the third problem was the most difficult and that it was generally more difficult to create pictorials because she had to put the views together mentally.

4.4.4.3. Participant 02 Textural Description

When asked how he felt about doing spatial problems in the second interview P02 stated that he was curious about the problems he would be doing, but he was not apprehensive. He added that he felt he was doing well in the course and did not think he would have any problems.

4.4.4.3.1. P02: Problem 1

P02 began the first problem by analyzing the object. He then drew the construction boxes for the three views. While he was working, he acknowledged that usually he has the TV on when doing homework. As he began drawing, he noted that he liked to draw the outer boundary for each view. He declared:

> ...basically the first thing I do once I have my construction boxes in place is I look at which parts of the construction boxes are going to be actual solid lines. I think, I like to, you know, like we use the construction boxes to sort of create a general outline of the space. I then like to sort of go around the construction lines and see which areas are going to be bordered, to then make, not only an outline of the space but an outline of

> my object and then kind of keep moving in making it more and more detailed.

P02 seemed very conscious of his tendencies, strengths, and weaknesses—he seemed very self-aware. For example, he made statements such as:

> Another thing I do a lot is that I sort of look at, I don't know, I look at it and sort of look at it and see if it looks dimensionally correct. I mean, sometimes when you draw something, I’ll be doing a circle and for some reason one of my boxes will be one square off. And you draw the circle and all of a sudden you look at it and you notice it’s lopsided. You instantly know you've got a problem and you need to, to see what's going on.

P02 completed each view before moving on to the next and he reviewed his work before doing so as well. Once he had completed the positive geometry in the front view, he moved on to the top view and then the right side view. As he worked on these views, I noticed that he fluidly worked across views; he used an already completed view to help himself on the one he was currently drawing. He was not just working from the pictorial; he was working from it, but also from the view that he had already created. Once he was completed with the positive geometry in all views, he went back and did the negative geometry.

After completing all of the views, P02 looked them over; "double-checking to make sure everything looked reasonable." He tried to account for all of the different surfaces, all the hidden lines, and "items of interest." Figure 4.11 shows P02’s finished drawing, which had no errors.

4.4.4.3.2. P02: Problem 2

After he looked at problem 2, P02 said:

> These usually, I wouldn't say are more difficult, but I have a tendency to take a little bit longer time and the majority of the reason for that is for the scaling and for the just conceptually seeing the object um, try to get an idea of, you know, how the faces are looking what exactly is going on.

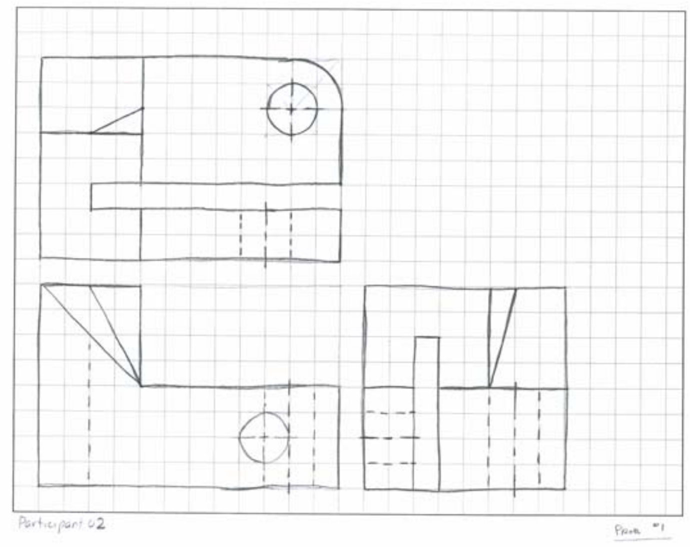

Figure 4.11. P02's completed problem 1 had no errors.

As he reviewed the object, he talked through it. As he did so, he acknowledged that one of the difficulties of working on pictorials was finding a starting place on the grid paper, as well as finding a reasonable starting point on the object. P02 admitted that he typically picked one point on the object to build from because it made it easier for him. As he talked through the object, he decided to start with the left-front edge of the object. He said:

> I am picking this point right here. Um, as my, my location which I guess on this one would be right here as well. That 's what I like to do, I don't typically circle it. I am just more doing it so, as I am discussing with you. I pick a, I pick a, I like to pick one point and just sort of build from that point, which typically makes it easier for me. Um, I am just kind of getting an idea of the shape of the object from that point. Already having two lines on here, I can see that if I wanted the object more centered I should have set it more to the right.

He acknowledged that his object was going to run off the page. While it was obvious that he could envision the object, he did not appear to have a process by which he could ensure, before he began, that the object would fit on the page.

As P02 approached the right-hand end of the object, he acknowledged that he was going to purposely skip it and come back to it, because he could see that it was probably the most complex part of the sketch. I wondered if this ability, the ability to skip over a difficult piece and come back to it, might be a sign of mental or problem solving maturity. Nevertheless, as P02 completed the left-hand and top U-shapes, he stopped for a moment to review what he had done. He said:

> Once again double-check everything. Geometry's looking appropriate. Looking back now I see I am missing a line here...I always like to double, double-check. My dad always said when you were like working with lumber, anything, you always measure twice, cut once. It’s kind of the same. I kind of try to use that same principle when I am doing this as well.

After completing the right-hand end of the object (see Figure 4.12), P02 acknowledged a sense of pleasure with how the solution was turning out:

> And see that now that I've got to this point, I am pretty pleased with the general shape of the object. Um, it’s pretty accurate compared to how I thought it looked before I started drawing. So I think all I really have left to do is to add my holes. I am the worst at drawing the oval holes....

Once he finished the negative geometry, P02 did a final check on the problem. He acknowledged that he looks for features and faces between the multiview and the pictorial he drew:

> Let's see. Well I seem to be, I think, completed with this one. And I'm just like, just like the previous one once again I am just looking at it, just looking for anything that I may have completely missed or something that looks totally disproportionate. You know, a feature that's not there or if like I forgot a, a face of anything. Something, you know, I typically do. I just sort of look for features and faces. I guess that’s it.

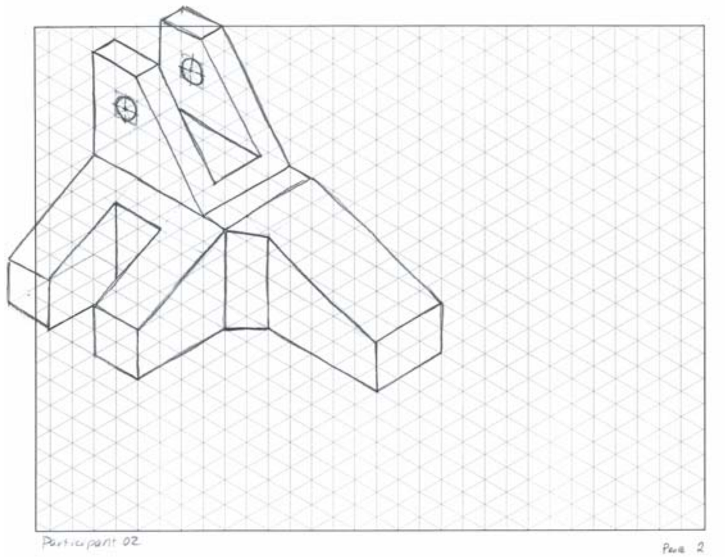

Figure 4.12. P02's solution to problem 2 had no errors except for its misplacement on the page.

4.4.4.3.3. P02: Problem 3

As P02 examined the third problem, he was immediately drawn to a feature he had not seen before (the hexagonal hole). However, it did not seem to bother him; he talked it through until he understood it. He went on to acknowledge that problem 3 was definitely more challenging:

> ...Yeah this is a little more challenging, picture here. I can see it, kind of, in my mind, I can see what it looks like. I mean, obviously I guess it's an L-shaped, the one side is cut out. It's got the hexagonal hole going through it and then you've got the circular holes going in the two directions going back. I mean, I mean in my mind I see it, now it's just a question of can I transfer it to a sheet of paper and make it look reasonable.

As 02 started sketching, he chose to start with the looped end on the right. As he began working, he admitted that problem 3 was "serious compared to the ones we've done in class." He went on to say:

> I think one of the most important things is, with this one, is just not get intimidated by the picture right off the bat.

As he continued to work, he encountered a feature that I put into the problem and asked how he should interpret it. As I designed problem 3, I specifically put one feature into it that could be interpreted in two different ways. P02 was actually the only one of two participants to notice this dualism, leading me to believe that he was likely one of the strongest in spatial ability amongst the high visualizers. The course data also supported this belief.

Once he had gotten the solution halfway complete, P02 stopped again to check himself. He said:

> There’s something going on here, too. It’s going to be coming down. Now I am sort of looking it over. I am fairly happy with my shape at this point. It looks a little awkward here because you've got this slanted line and then you've got the vertical face behind it. Um. I guess I'd probably start putting in some of my other [negative] geometry now.

After putting the negative geometry in the drawing, P02 did a final check of his pictorial to see if it looked "reasonable." Figure 4.13 shows P02’s final solution for problem 3. Aside from being slightly off-center, he had no errors in his solution.

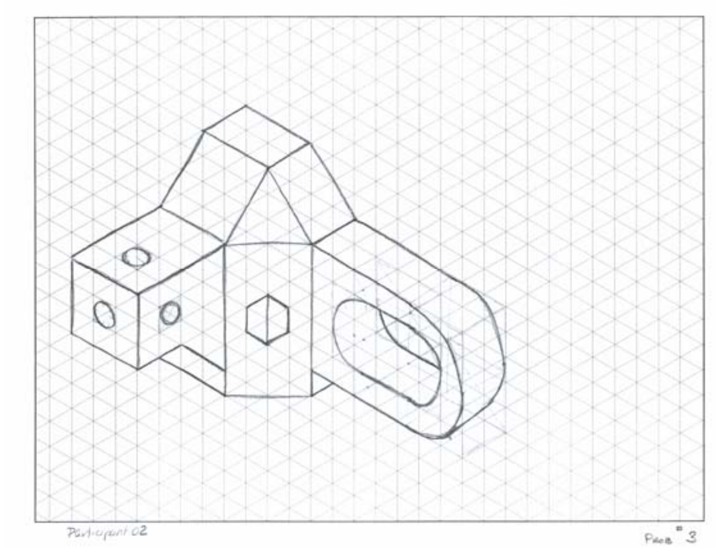

Figure 4.13. P02’s correct solution for problem 3.

4.4.4.3.4. P02: Summative Questions

P02 acknowledged that he thought problem 3 was the most difficult. He also voiced that he thought that multiviews were easier than pictorials. He stated that he thought it was "easier to think of a certain side of an existing 3D object than to take pictures [multiviews] of the side and then form the 3D object in your mind."

At the end of the interview with P02, I provided him with a recommendation on how to center his pictorial views at the start of his drawing. Beyond that, P02 had successfully completed all three exercises with no errors.

4.4.4.4. Participant 02 Structural Description

P02 was able to solve all three of the applied tasks from the second interview accurately. As he worked, he was very analytical and self-aware. He seemed to have a defined process for the creation of both multiviews and pictorials. However, a consistent problem for him seemed to be getting his pictorial drawing centered correctly on the page. Throughout all three problems, he seemed to be able to communicate his thoughts and actions fluidly. Often he would stop frequently to review his work (checking for errors). Moreover, although he reported problem 3 to be the most difficult, he acknowledged that the most important thing was not getting intimidated. Rather, work out the problem, piece-by-piece, and let it come together naturally.

4.4.4.5. Participant 03 Textural Description

When asked how he felt, P03 reported that he "felt kind of nervous" when he found out that interview 2 would be applied problems. He said he felt this way because he "figured that there would be at least one of the problems that would be something I could not visualize." However, he also described the feeling as "curious" as well. He reported that he was "fairly comfortable" with the course sketches, except for minor problems with section and auxiliary views.

4.4.4.5.1. P03: Problem 1

After quickly looking at the first problem, P03 immediately began drawing. He drew the construction box for the front view, the positive geometry, and then the negative geometry. He did the same with the top view and the right side view. Like P02, P03 seemed to be able to easily articulate when he was thinking and doing. He also acknowledged that he checked his work often, by looking across views and comparing it to the pictorial.

Once completed with problem 1 (see Figure 4.14), P03 did one final check of his views because, as he said, "I often forget many things." P03's solution to problem 1 had no errors.

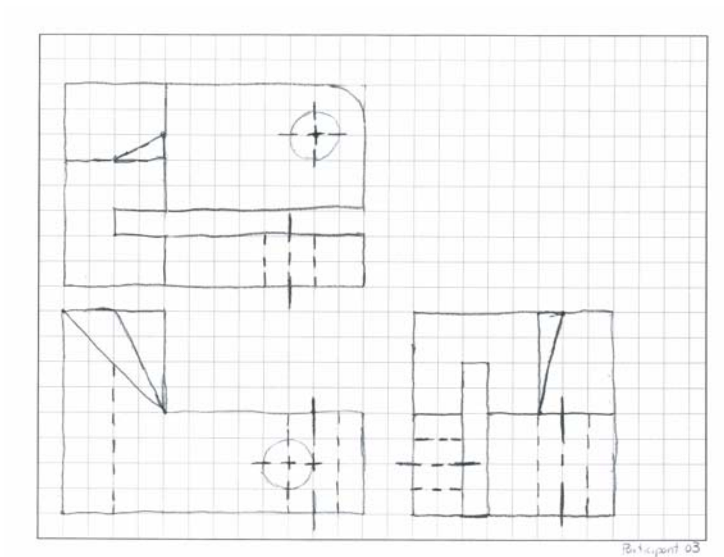

Figure 4.14. P03's solution to problem 1 had no errors.

4.4.4.5.2. P03: Problem 2

Initially, P03 said that the second problem was "a confusing one," but within a few moments, he said it was "not too bad." He went on to describe how he tried to create a mental representation of the object:

> First view I always look at is the frontal. I always try to match up the frontal with the top view and try to start working back...So I got to think of a good starting point. That's always probably the hardest part of it.

Like P02, P03 started by finding a point on the object to use as a reference. He then proceeded to choose a point on the grid paper to start drawing. P03 started the problem by drawing an isometric box.

P03 started drawing the pictorial by focusing on the left-front edge. As he worked his way around, he skipped the compound angle and focused on the top U-shape. As he was trying to determine how to do the compound angle, he admitted, "I never figure out whether I am right or wrong until it's just about over." Even while communicating this sense of uncertainty, though, it seemed that he was relatively confident that he was doing it correctly. P03 also acknowledged that he feels his biggest weakness is his drawing skill. While he can see the object in his mind, he said, "Most of my flaws are limitations to my drawing skill. I don't have good drawing."

After completing the positive geometry, P03 stopped and reviewed his work before adding the negative geometry. After completing the negative geometry, he again reviewed his drawing before saying he was done. Figure 4.15 shows P03's solution, which was correct. However, like P02, P03 had difficulty getting the object centered on the page.

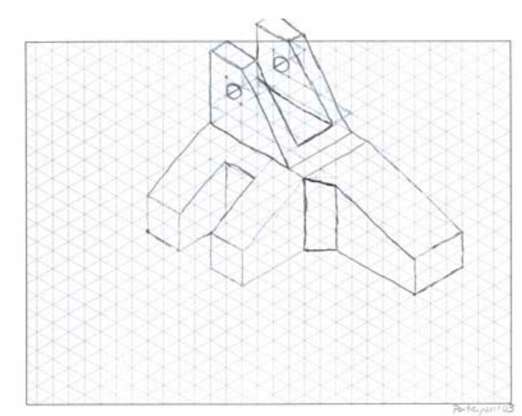

Figure 4.15. P03's solution to problem 2 that, while off-center, was correct.

4.4.4.5.3. P03: Problem 3

Upon initially viewing problem 3, P03 acknowledged, "the worst part of a lot of these problems is like, sometimes it looks too complex. You can’t really focus." However, after reviewing problem 3 for a few moments, he stated that it was "starting to look a little easier." He then made known his biggest difficulty with the pictorial problems:

> I guess the hardest part is finding a starting point. All right, this is going to be hard to draw. Because it’s shaped in this type of L-type format. I would assume I could pick my point, with it going over and up, it should be centered. So I'll guess the point to start with is right here. This is tough.

P03 decided to start on the looped end (right end) of the object. He then moved onto the top plane and its angular features. As he worked on the center of the object, P03 also noticed the dualism in the center of the object. In addition, like prior problems, he stopped twice while drawing to check his work. In addition to being off center, P03’s solution had one error. He did not draw the hexagonal feature correctly. However, this was a minor issue as Figure 4.16 shows.

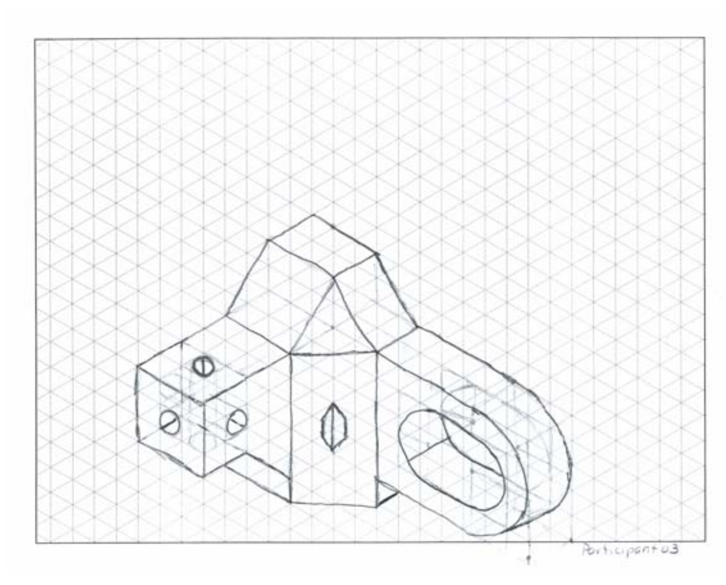

Figure 4.16. P03’s solution is correct except for its placement on the page and the hexagonal hole.

4.4.4.5.4. P03: Summative Questions

When asked, P03 said that problem 3 was the most difficult because it "seemed like it had more planes, more shapes, and more holes than all the other ones." P03 acknowledged that his initial reaction to problem 3 was due to all of the hidden lines. P03 said he could not tell whether multiviews or pictorials are more difficult spatially. He declared:

> I don't know. I can't really compare those up to each other. It always seems like, you know, of course I am going to say it was hard for me to do this [problem 3] than it was to do this [problem 1] but honestly I think they are both just about the same amount of work and effort. I mean you have to be able to visualize something like a 3D object to be able to put it into multiviews, whereas you have to visualize the multiviews to put it into 3D. Either way, I mean, if I am looking at this object [problem 3] I could see this [his solution to problem 3] like you know, I could like look at it this way, and see you know that plane and then the other plane.

P03 acknowledged that the problems were not necessarily hard. He seemed to have confidence. He stated, "I may get confused on it but...I can usually" figure it out.

At the conclusion of the interview with P03, I provided him feedback concerning how to center the pictorial drawing on the page. He had correctly solved all the problems, and while I acknowledged that, I provided no other feedback.

4.4.4.6. Participant 03 Structural Description

P03 acknowledged some initial apprehension and curiosity toward the applied problems in interview 2. However, once doing the problems, he seemed relatively comfortable and confident in doing them. On all of the problems, P03 checked himself frequently to ensure he was not making any errors. When doing both of the pictorial sketches, however, he did not get the objects centered correctly. P03 acknowledged several times that when doing pictorial sketches, finding the starting point on the object was the most difficult part for him. While he said he could not tell whether drawing multiviews or pictorials is harder, he relayed that even if he got confused in a problem he could usually figure it out. Even though he seemed to lack confidence, for example, in his drawing skill, his confidence in being able to figure out complex problems was evident.

4.4.4.7. Participant 04 Textural Description

As noted earlier in this chapter, the audio recording of P04's think aloud procedure was lost due to a recording error. However, observation notes and her solutions were available. In an effort to provide some data about her problem solving approach, the following three sections are based upon these two data sources only.

4.4.4.7.1. P04: Problem 1

P04 began problem 1 by creating the construction boxes. She did the positive geometry and then the negative geometry in the front, top, and then right side views. She completed each view in its entirety before moving on to the next. Based on the amount of time spent, P04 seemed to have some difficulty with the oblique plane. Figure 4.17 shows her solution to problem 1. She made one error, which was a missing line at the bottom of the slot in the right side view.

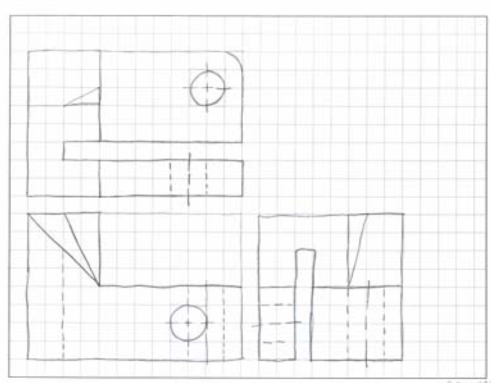

Figure 4.17. P04's solution to problem 1 that had one missing line in the right side view.

4.4.4.7.2. P04: Problem 2

P04 began the second problem by focusing on the frontal U-shape. She was initially confused by the angles visible in all three views. She began creating another view (left side view; off the top view) on the multiview drawing that she said the TA showed her how to do.

To begin problem 2, P04 created an isometric box and then focused on creating the frontal U-shape in isometric. It appeared that P04 was decomposing the object into more manageable chunks to be able to create the solution. She had significant difficulty with the right side of the object (the compound angle). To help herself, she drew the right side view on the right end of the isometric box she had constructed. It was not until she was doing her final review of her solution (which was missing the compound angle) that she actually figured it out correctly. Figure 4.18 shows P04's solution to the second problem. There are a few errors evident, such as a missing line in the frontal and top U-shaped features. It was also becoming apparent at this point in the data analysis that all students have a difficult time centering the object on the page (P04 was the third high ability participant who had this difficulty).

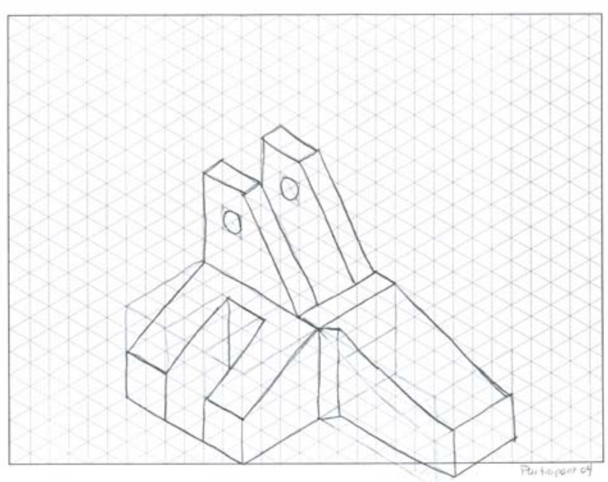

Figure 4.18. P04's solution has several errors in the U-shaped elements and it was not centered on the page.

4.4.4.7.3. P04: Problem 3

P04 was intimidated when given problem 3. She studied it intently for quite some time and it was evident that she was looking across views, trying to picture it in her mind. While she seemed to have difficulty selecting a starting location, she settled on the looped, right-side end of the object. She then moved to the other end of the object. In my notes, I stated that her confidence seemed to build with each additional piece she added. However, due to time limitations she was unable to complete the solution, as shown in Figure 4.19.

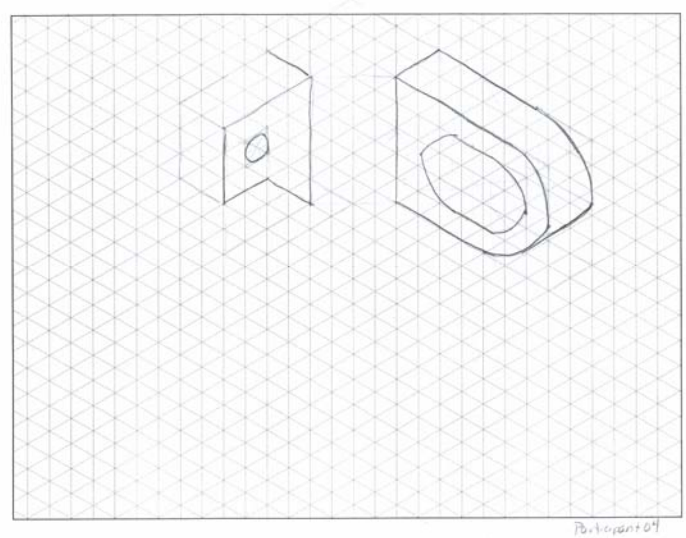

Figure 4.19. P04's confidence grew as she added each piece, however, time limitations prohibited her from finishing the problem.

4.4.4.8. Participant 04 Structural Description

While she made some errors on her solutions, P04 was able to work her way through the three problems. Like other participants, she had difficulty centering the pictorials so that they would fit on the page. My observation notes acknowledged that P04 seemed to be logically breaking down the latter two problems into more manageable chunks. Additionally, she was initially intimidated on problem 3, but steadily got more confident as she worked through the problem.

4.4.4.9. Participant 05 Textural Description

P05 reported that she was a curious about the problems in interview 2, but not apprehensive. She said she wondered "if they were going to be extremely difficulty or not..." P05 acknowledged that she sometimes got confused because of her construction lines, but aside from that, she really was not having any difficulties in the course.

4.4.4.9.1. P05: Problem 1

P05 started the first problem by doing a quick mental analysis of it:

> Ok. Out loud. This is going to be difficult. Ok, um, typically I try to figure out, ok, I am looking at it thinking, just trying to visualize the object itself. First, so I know that there's going to be, you know, a hole going through here...so this hole’s going to go all the way through. There’s a slot right here. This is going to be an oblique surface. Um, that’s probably about it. Ok, then I would start by saying that this is going to be my frontal view.

P05 started by drawing the frontal construction box and did both the positive and negative geometry in the front view before moving on to the top view. As she worked on the top view, it became evident that P05 was doing a lot of reference checking between the view she was working, the one she had already done, and the source pictorial drawing. Of this she said, "I try to double check myself a lot, but I still mess it up sometimes." As she worked on the right side, she again referred to double-checking her measurements:

> The circle should still be two. Yep. Ok. It’s two and yep, ok. I am sure "yep" and "ok" tells you a lot, but I just keep double-checking to make sure I don't make my measurements wrong.

Once she was completed with problem 1, P05 did one final review comparing her multiviews to the pictorial:

> It's hard talking out loud, I am looking at holes and making sure there is a gap extending up into the incline. I have the gap drawn in, and the oblique is angled in every view. Yep, ok. I think am done.

Figure 4.20 shows P05's solution to problem 1. She had no errors in her solution.

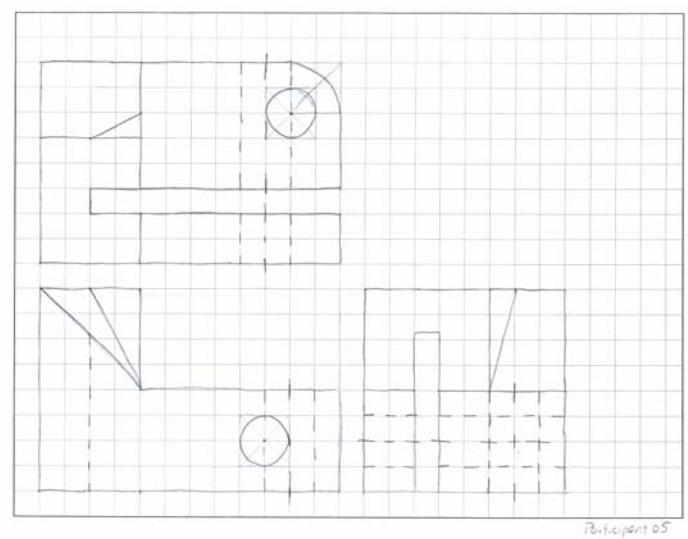

Figure 4.20. P05's solution to the first problem had no errors.

4.4.4.9.2. P05: Problem 2

As P05 began the second problem, she started by trying to visualize the object. She acknowledged some initial difficulty visualizing the object:

> Trying to get an idea of what this thing looks like. All right. Typically, cause this one I am having a little bit of a problem visualizing altogether. I can see pieces, like from this side one, I can see that this corresponds to this, um, and the holes. But what I am going to start by doing is sketching the very front and sketching everything that is on the very front of the object, which is just going to be this.

P05 described starting on the left of the object, drawing the frontal planes that are coplanar with the edge of the isometric box she had created. From there she was able to create the entire left U-shape.

She then moved to the right-end that contained the compound angle. After working on it and having some difficulty, she decided to move to the top and come back to the compound angle. She seemed comfortable skipping it and coming back to it later. She said, "Maybe sketch something else and then come back."

After successfully completing the top, P05 returned to the right-hand end of the object. After spending considerable time trying to figure out the compound angle, she stopped and was unable to complete it. Figure 4.21 shows her solution to problem 2.

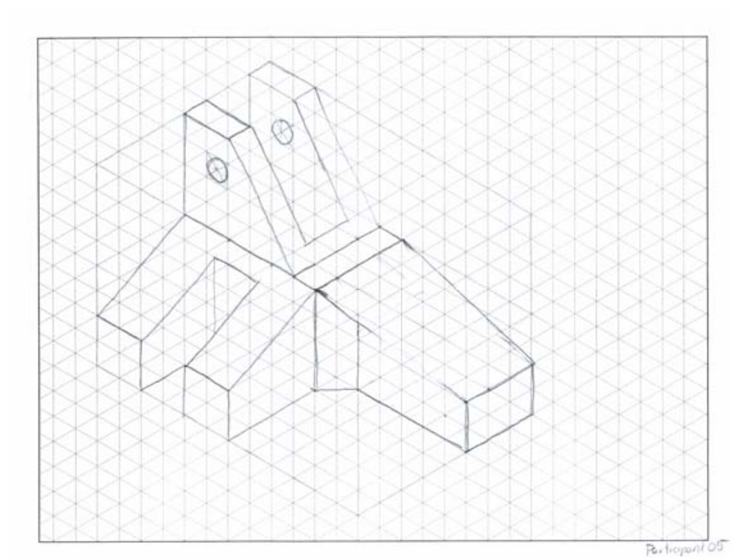

Figure 4.21. P05 was unable to solve the compound angle on the right-hand end.

4.4.4.9.3. P05: Problem 3

Due to a time limit on interview 2 and the amount of time she spent trying to solve problem 2, P05 did not have long to work on problem 3. She began by doing a quick review of the problem and started drawing almost immediately. She created an isometric construction box and started on the top-rear of the object. After only 10 minutes on the problem, I had to stop her due to the time constraint. Figure 4.22 shows her incomplete solution for the third problem.

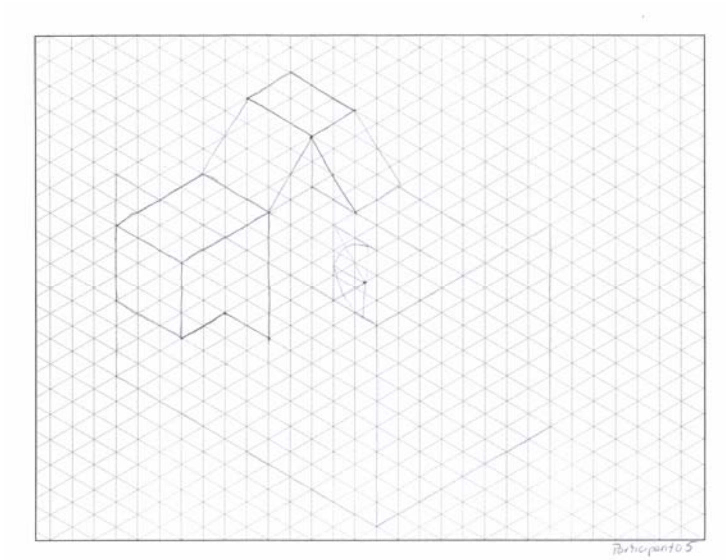

Figure 4.22. S05's incomplete solution to problem 3 (due to time).

4.4.4.9.4. P05: Summative Questions

When asked, P05 said that multiviews are easier because all you have to do is "flatten up" each view:

> ...you already understand the object that is trying to be conveyed to you. You can see the object and you like flatten it up this way, flatten it up this way, flatten it up this way. With the iso[metric], I try to get the big picture first and sometimes you can't see it right away. So you have to, it's more like working in the dark.

I acknowledged to P05 that she seemed to be able to let go of a part of a problem (a part she did not understand) and move on to another part, believing she could come back later and figure out the confusing part. She said:

> You've got to try for a while, but eventually, you are just getting yourself worked up and your are not getting anything done.

At the end of the interview with P05, I provided her a process for solving the compound angle in problem 2. I also encouraged her to watch small errors, such as the ones she made in problem 1.

4.4.4.10. Participant 05 Structural Description

P05 successfully completed problem 1 with no difficulties and most of problem 2. Although she only completed part of problem 3, I believe she would have completed it if given another 15 minutes. As P05 worked, she noted that she had a tendency to double-check her measurements across views and the solution several times. This is something that seemed to be a trend amongst the high visualizers. When she got to the second problem, she had a determination to solve the compound angle and did not appear to get frustrated even when she was unable to arrive at the correct solution.

4.4.4.11. Participant 06 Textural Description

P06 seemed indifferent when asked how he felt about applied problems in interview 2. He said, "We've been doing them in class so and I am a little better than I used to be so...." From there, I presented him with problem 1.

4.4.4.11.1. P06: Problem 1

P06 began by doing a quick analysis of the isometric pictorial given to him:

> Well what I am first thinking is I always go through ah, I always start on the front side, or the left side whatever you call it so, I am looking at this height here and kind of comparing to the height back here and trying to get a sense for what is going on so...

P06 started problem 1 by drawing out the construction boxes for all of the views. He then began drawing the object boundaries. P06 stated "Ok. Now I am going to, going to look and kind of draw out the lines you can see easily, so I am not worried about hidden lines." He drew the positive geometry and then the negative geometry before moving on to the top view. He did the same method in the top view before moving onto the right side view. Except for a missing line in the right side view, P06 correctly created the multiviews, as shown in Figure 4.23.

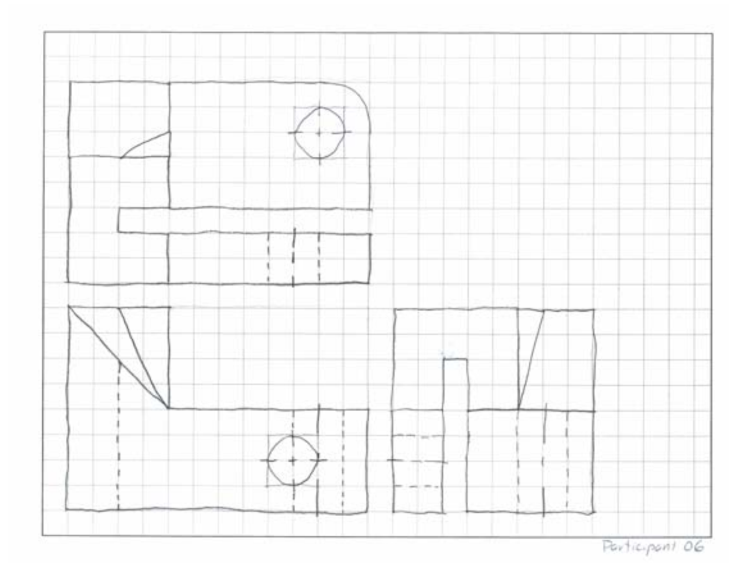

Figure 4.23. P06's solution to the first problem was missing one line in the right side view.

4.4.4.11.2. P06: Problem 2

P06 started the second problem by drawing the right-end of the object. He seemed to have little difficulty figuring out the compound angle. From there, he worked around the object, always beginning with the coplanar faces and connecting them to what he had already drawn. Based on the way he was drawing the object, it appeared that he had broken the object down mentally into manageable pieces that he drew on the paper, piece-by-piece. Figure 4.24 shows P06's solution to the second problem.

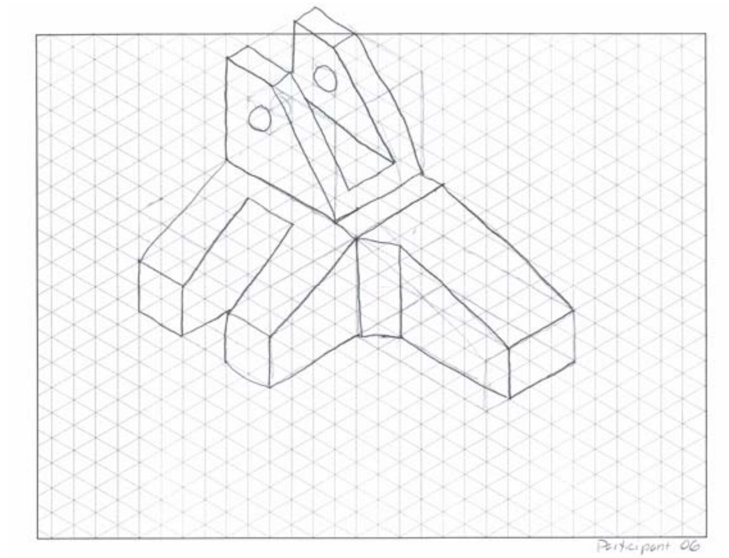

Figure 4.24. P06 correctly solved problem 2.

4.4.4.11.3. P06: Problem 3

Problem 3 was designed to have a "high intimidation" factor due to the number of hidden lines within it. However, that seemed to have no effect on P06. He began on the right-hand looped end by constructing a prism and then the individual circular features. Again, as he moved around the object, he started with the planar features that were coplanar with the ends of the box and moved toward the center. The last feature he drew was the protrusion on the left-hand end. While his hexagon, shown in Figure 4.25, was misshapen, he did recognize that the element was simply a hexagonal hole that went through the entire object. And, like other participants, he had difficulty centering the object on the page.

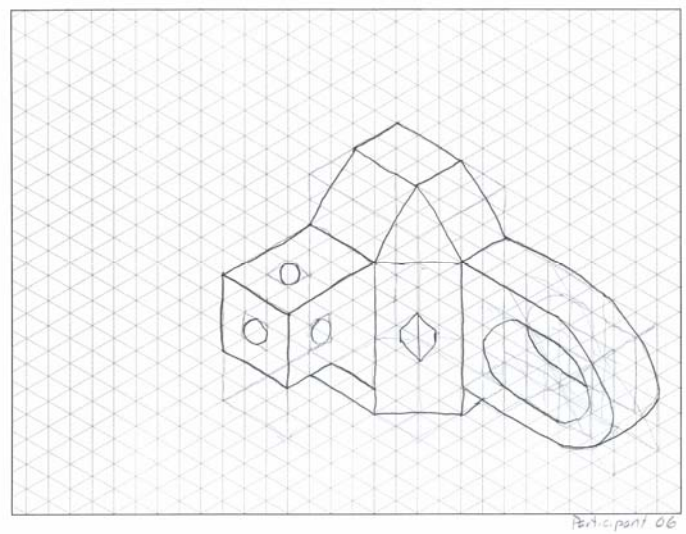

Figure 4.25. Although not centered on the page, P06 correctly solved problem 3.

4.4.4.11.4. P06: Summative Questions

P06 reported that he thought that multiviews were easier to create because "you can see the whole piece," whereas creating the pictorial required "more horsepower to get into it" because creating "3D off of 2D...is a little bit harder." He stated:

> I, personally think isometric, there's less rules, there's less for me to screw up. I always forget tiny things. So like a multiview, I will forget hidden lines, little lines, and things. But like going in between them like, I would say mentally it's easier from isometric to multiview because it's just like you can see the whole piece and it's easier. I mean, it's like in 3D so it's easier to look at and then to break, and you can just look top, that's really easy to look at. But when you go from a multiview to an isometric, you have to, you know, create it 3D off of 2D, which is a little bit harder, at first it's a little more mentally. You have to put a little more horsepower into it, but then like once you, you get rolling with it, it gets a little bit easier. So it's kind of like give or take sometimes.

At the end of interview 2, I provided P06 with feedback on how to center his isometric sketches so that they would fit on the paper. I also encouraged him to watch for small mistakes, such as his one missing line in problem 1.

4.4.4.12. Participant 06 Structural Description

P06 seemed to have little difficulty with any of the problems in the second interview. On the latter two problems, while he did not vocalize how he had deconstructed the object mentally, it was evident by the way he drew a part at a time that he had indeed mentally decomposed the object into smaller pieces. As he worked on each of these pieces, he began drawing them by starting with the features or planes that were coplanar with the major planes of the isometric box. He then worked on known entities; he drew lines that were collinear with the box edges and then non-collinear entities. He seemed to exhibit little or no frustration or intimidation in any of the problems. Like other high ability participants, he double-checked himself often and had difficulty centering the isometric pictorials on the page.

4.4.5. Second Interview with the Low Visualization Group

The following sections provide the textural and structural descriptions for each of the low visualization interviewees.

4.4.5.1. Participant 07 Textural Description

When asked, P07 said she did not really give much thought to doing applied exercises in interview 2. She said that she had been finding the exercises in the course accomplishable. Due to some prior experience, P07 found the isometric drawing examples easier than the multiviews.

4.4.5.1.1. P07: Problem 1

After receiving problem 1, P07 immediately started drawing. She began by creating the construction boxes for all views and then the positive geometry in the front view. She completed the hidden geometry in the front view and then used a similar process for the top and right side views. As shown in Figure 4.26, her solution was correct except for missing hidden lines in the front view.

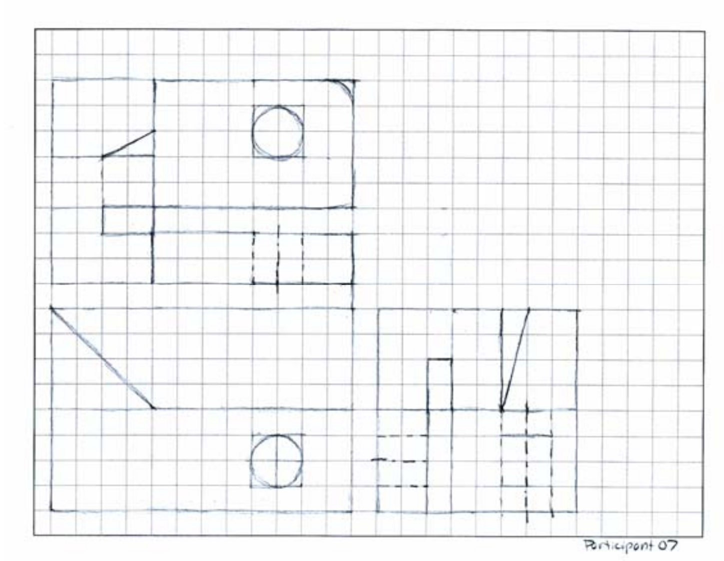

Figure 4.26. P07's solution to problem 1 was missing hidden lines in the front view.

4.4.5.1.2. P07: Problem 2

When given problem 2, P07 again immediately started drawing. She created an isometric construction box, but then was unable to go much further. After sitting for several moments, I stopped her and asked her to complete alternative B, which she completed (see Figure 4.27).

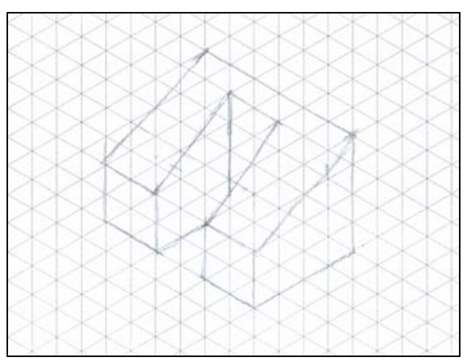

Figure 4.27. While unable to complete problem 2, P07 was able to solve alternative B correctly.

4.4.5.1.3. P07: Summative Questions

Upon review, P07 said she could not figure out what she was doing wrong with problem 2. Originally, she said she thought doing the isometric view was easier than doing multiviews because her art and design classes had required she create pictorials. However, in problem 2 it seemed apparent that she was having significant difficulty. Beyond the isometric construction box, her working solution to the second problem was nothing more than random sketch lines. And, even with alternative B, it took her some time to figure out what the object looked like.

At the conclusion of the second interview with P07, I spent a significant amount of time providing a systematic process for the creation of pictorial drawings from multiviews. Part of this was focused on how to center a pictorial on the page, but it was primarily aimed at having a process that she could use when she could not see the object mentally. This process is described in the next chapter. I also encouraged P07 to check her work before finishing, so that she could catch small errors, such as those she made on the first problem.

4.4.5.2. Participant 07 Structural Description

P07 had significant difficulty with the isometric pictorials, even though she thought they would be easy for her. In all the problems she did, she did not take much time trying to visualize the object; she said very little during the initial presentation of the problem and spent less than a minute or two looking at them before she started drawing. Also, she did not take the time to review her work prior to saying she was done with problem 1. As she drew the multiviews, she worked almost exclusively from the problem stimulus, and seldom across her own views. Had she looked across her solution views, she likely would have noticed the missing hidden lines in her front view. On the pictorial creation, she had significant difficulty visualizing even the simple object presented by alternative B.

4.4.5.3. Participant 08 Textural Description

As noted earlier, P08 was a non-native English speaker, which caused some difficulties in understanding his spoken comments and likely was the reason for brevity of them. Nevertheless, he seemed to be unconcerned or unaware what the applied problems in interview 2 would be. He stated that he wondered if it might be like the MRT test or some other spatial test.

4.4.5.3.1. P08: Problem 1

P08 began drawing the views for problem 1, but did not create construction boxes. He began with the positive geometry in the front view, and then completed the negative geometry. He proceeded from front view, to side view, to top view, seldom working across views. Rather he referenced the pictorial view perpetually. Except for a missing line in the right side view and misaligned holes in the front view, P08 successfully completed the first problem as shown in Figure 4.28.

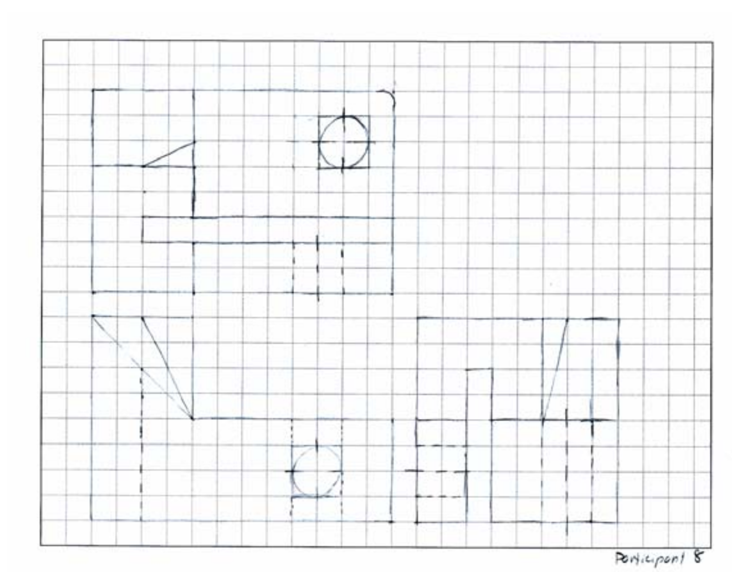

Figure 4.28. P08 solved problem 1 correctly except for the misaligned holes in the front view and a missing line in the right side view.

4.4.5.3.2. P08: Problem 2

When presented with the second problem, P08 spent little time trying to visualize the object. Instead, he immediately drew the isometric construction box and started drawing the multiviews on the box, as shown in Figure 4.29.

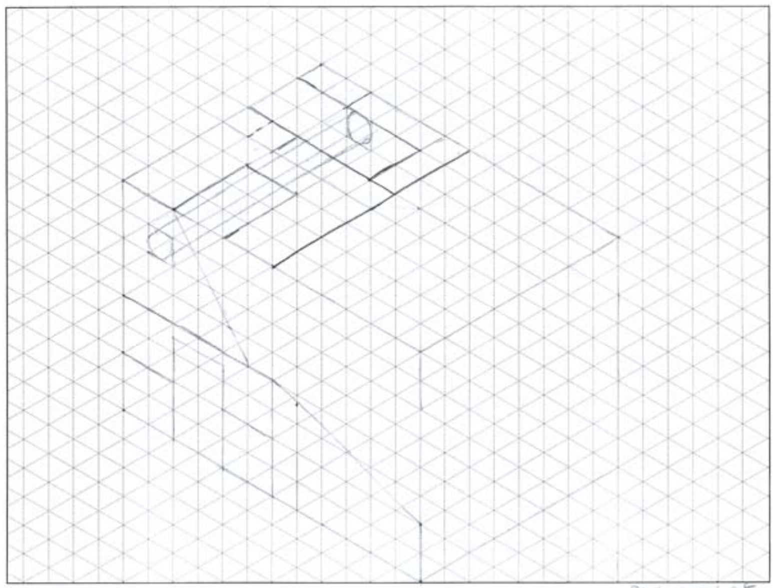

Figure 4.29. P08 began to solve the second problem by placing the multiviews on the isometric construction box.

I let P08 continue to draw the views for about 15 minutes, but then realized he was not going to be able to solve the problem. I then presented him with alternative B. He began drawing and almost completed alternative B correctly, but then he erased it and redrew the incorrect object is shown in Figure 4.30. When he completed the drawing he said, "I know something is wrong. Something is wrong."

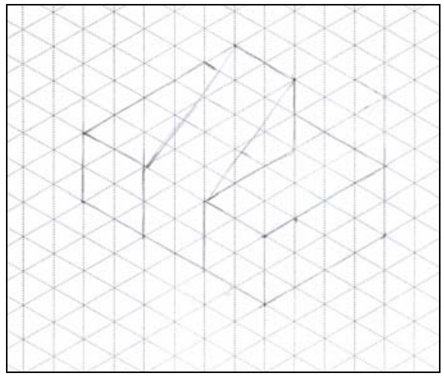

Figure 4.30. When given alternative B, P08 was not able to draw the object correctly.

4.4.5.3.3. P08: Summative Questions

P08 said that he thought that it is easier to create the multiviews than the pictorial. He said, "The multiviews doesn't give any picture. With the isometric, you have the object already and so it is easier to imagine the multiviews."

At the conclusion of the interview, I provided P08 with feedback. First, I encouraged him to double-check his work to make sure he did not make small errors, such as those he made in problem 1. I then spent the remainder of the time outlining the process for the creation of pictorials from multiviews.

4.4.5.4. Participant 08 Structural Description

P08 had significant difficulty with the creation of the pictorial views. He seemed to struggle with visualizing the object and had no method for figuring out the solution on the paper. Compounding matters, he was a non-native English speaker and it was evident throughout the interview that he had a hard time communicating what he was thinking, and, at times, interpreting what I was saying.

4.4.5.5. <u>Participant 09 Textural Description</u>

To open the interview, I asked P09 what she thought when I told her that she would be doing applied problems. P09 said she was not too worried about the applied problems in interview 2; she thought they would just be like the homework problems.

4.4.5.5.1. P09: Problem 1

After giving her the problem, P09 spent little time examining the problem. She immediately started drawing a construction box for the front view and then the visible outline of the object. Before finishing the front view, she moved on to the top view. She acknowledged that she was having difficulty talking aloud while she was working. In the top view, she again drew the object boundary and then added the slot and circles. She then completed the boundary and other visible features in the right side view. To finish her drawing she added the dashed lines for the holes in all views. However, there were several things that she forgot, as shown in Figure 4.31. The top view is missing the oblique surface and the front view is missing the oblique surface and the dashed line representing the slot. She took little time reviewing her work before giving it to me, saying she thought she was done.

4.4.5.5.2. P09: Problem 2

Upon receiving problem 2, P09 acknowledged that it was much more difficult. She said, "Hmm. This one is little harder to visualize for me, but...insane." She began by drawing the isometric box, as shown in Figure 4.32, and a portion of the top view in the top plane of that box. Although she worked for another few minutes on the problem, it was apparent that she was not sure what to do beyond what is shown in Figure 4.32.

Before giving P09 one of the alternative problems, I asked whether she could see problem 2 in her mind. She responded:

> Sort of, but not really. I think it helps now that I have the cube on the paper, I can see it better, but like when I first, just looked at the multiview, I was like, "Ok. I really don't know what that is going to be. We'll see if I can draw it." Like it doesn't look like anything that would be a familiar everyday

object or something like that. It's a little, that makes it a little more difficult...Like I thought I was getting somewhere and then I lost it. Hmm...This is really hard for me.

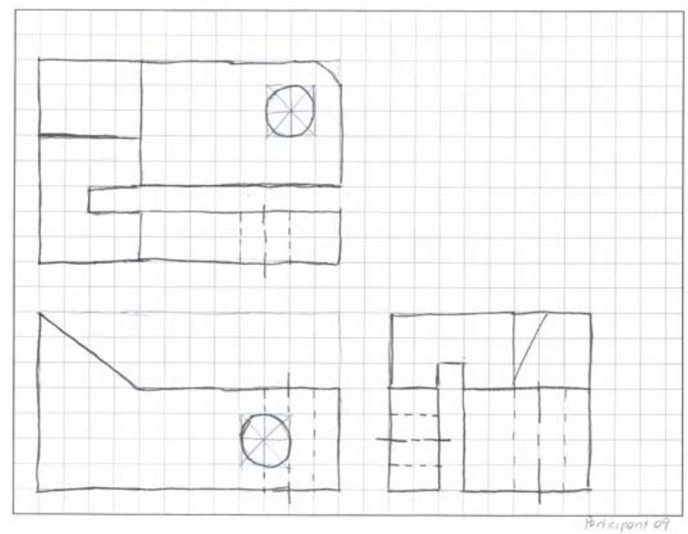

Figure 4.31. In the first problem, P09 missed several items across all three views.

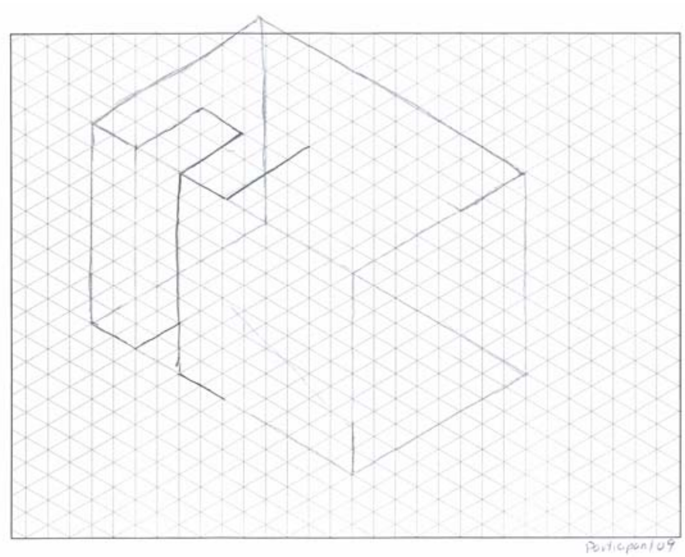

Figure 4.32. P09 began by projecting a feature from the top view.

I then gave P09 alternative B to solve. With a sigh, she drew the construction box for the object. She started on the top of the object, just as she had done with the second problem. From there she was able to project down and find the pictorial of the object, as shown in Figure 4.33. Her solution was correct but she had one extraneous line darkened, which she did acknowledge should not have been darkened.

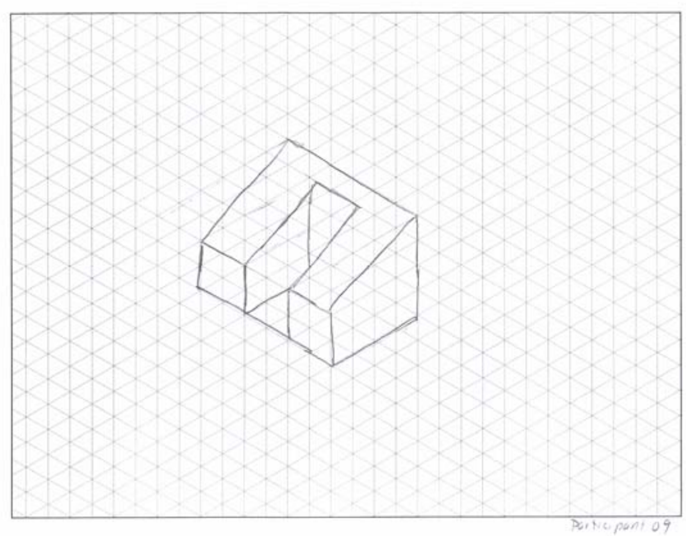

Figure 4.33. P09 was able to solve alternative B correctly.

4.4.5.5.3. P09: Summative Questions

After completing alternative B, I asked P09 if she thought these exercises were harder than the homework. She said:

> No, I think like, I think um, they are probably on the same level as the homework. I just think the time constraint is, is, normally like I'll go online and look at the assignment and then I will think about it for a while and then I'll come back to it a few hours later... I try to think about it and spend a little more time trying to see than just see this and ok draw it, that kind of thing.

Concerning the relative difficulty of multiview to pictorials, P09 reported:

> I think doing the multiviews is easier because I can already like, you have the 3D object and you can see it. I am not having to come up with my own picture of it. I think that, yeah, I think that multiviews are easier.

At the conclusion of the interview, I instructed P09 on the process for creating pictorials from multiviews. I also taught her how to center her pictorials on the page. I directed her to be careful not to make simple mistakes on her multiviews. She acknowledged that by doing a final review or check, she could avoid such errors.

4.4.5.6. Participant 09 Structural Description

P09 struggled a great deal with the isometric drawings. She acknowledged that it was important that she have the time to be able to think about the problems quite a while before she sat down and tried to draw them. As she worked on the isometric pictorials, it was evident that she was getting frustrated (by both body language and facial expression). P09 seemed to be unable to visualize the object and she really had no process that she could use to draw the object on paper either. Additionally, it was evident from her multiviews that she missed several details in the drawings also.

4.4.5.7. Participant 10 Textural Description

P10 reported that he was not overly concerned about doing applied problems in interview 2. However, he said jokingly that it was like "Oh good, more CGT work. [Laughs] Pretty much it." He went on to say his only concern was having enough time to do the problems. He admitted:

> I, I, the thing I'm worried about, not necessarily worried, I just know I take my time with things and, ah, I'm just thinking this person watching [will think], "Hurry up and get it done!"

After reassuring him that that was not the case, I presented him with the first problem.

4.4.5.7.1. P10: Problem 1

P10 immediately looked at the problem and admitted:

> Ok. The first thing I guess I am looking at here is the general dimensions, counting how many blocks, see how my proportions are going to be. Oh, gosh...You probably see me counting and recounting, cause I'm picky...

I inquired if he double-checks himself a lot. He reported:

> I do that a lot. I am always afraid I'm going to miss something. I would rather check it too much than not enough and have something screwed up....

As he drew, P10 started by creating the construction box for the front view and creating the positive geometry within the view. He completed the entirety of the front view (including negative geometry) and then moved on to the top view and right side, respectively. He saved the oblique plane in all views for last.

One of the things I noted in my observation notes was that he did not appear to be working across views as he created subsequent views, that is, he predominantly looked at the pictorial for each view created. In actuality, this commonality seemed to be dependent on visualization ability. High visualizers seemed to look across views more. However, I hesitated to focus too heavily on this at the time.

As P10 finished the views, he acknowledged, "I guess overall I thinking this is fairly easy." He stopped and did a final review of this drawing and acknowledged that he was done. Figure 4.34 shows his final drawing for problem 1. He did miss a line in the top view (which he had originally drawn) and he drew the multiviews on the border of the sketch paper.

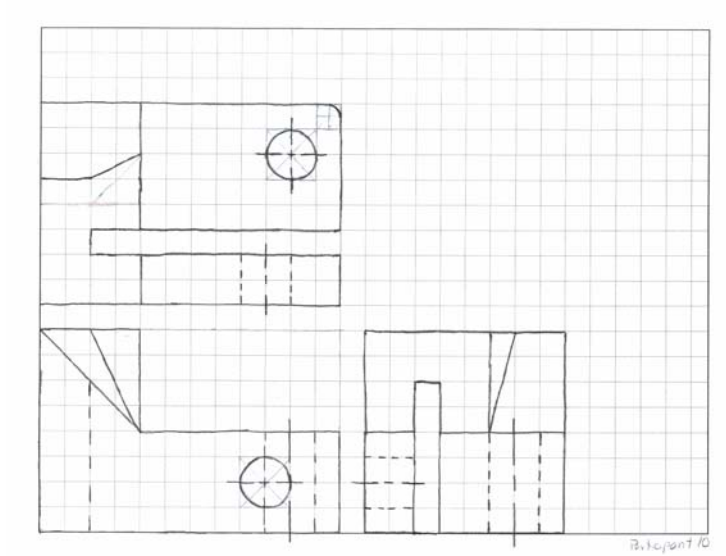

Figure 4.34. Except for placing the views on the page border, P10 solved the first problem with only one missing line in the top view.

4.4.5.7.2. P10: Problem 2

P10’s first response to problem 2 was, "And this one I can tell you right now I'm going to look at for a minute or two." After a few moments, he said:

> I think, I'm trying to see what the part looks like, I'm not sure how the, oh, ok, I got that... I guess the easiest thing to do would be draw some sort of box and at least give me the right dimensions and give me somewhere to start.

While he initially had difficulty centering the object on the page, once completed he started the drawing on the left-front portion of the object. After drawing the entire left-front piece, P10 stopped to check his drawing against the multiviews. He then moved to the right-front section, but stopped when he noticed the compound angle. However, after completing the top, P10 returned to the compound angle and finished the drawing. As shown in Figure 4.35, P10 correctly solved problem 2, except for two missing lines in both of the U-shaped elements.

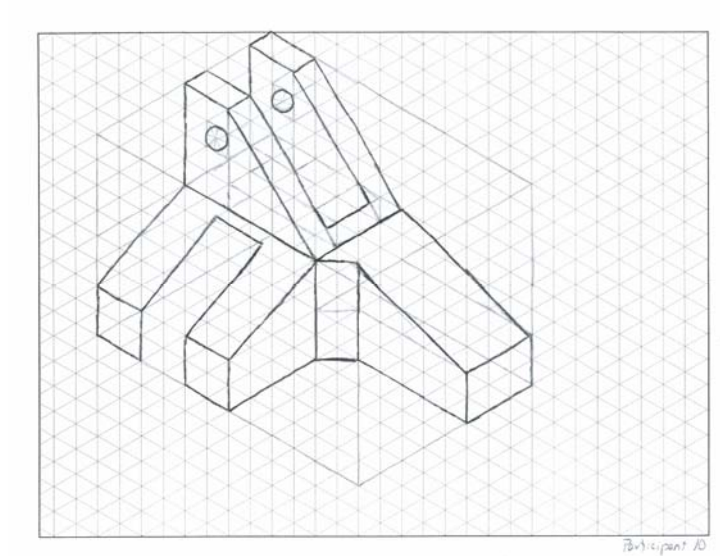

Figure 4.35. Except for two missing lines, P10 was able to solve the second problem correctly.

4.4.5.7.3. P10: Problem 3

When posed with problem 3, P10 only had about 10 minutes of time left. Nevertheless, P10 admitted:

> Hmm, Hmm, Hmm. Well it's definitely a complex one. First thought this might be a little above my skill level. [Laughs]...Well, I guess, I can see right off the bat, you know, the size I need to make so I'll go ahead and sketch out a construction box.

After creating the construction box, P10 decided to start on the right, looped end of the object. He constructed a box to contain the feature and then created the upper inclined surfaces to where the top of the object is coplanar with the isometric box. At that point, P10 ran out of time in interview 2 and I stopped him. Figure 4.36 shows the sketch that P10 was able to complete.

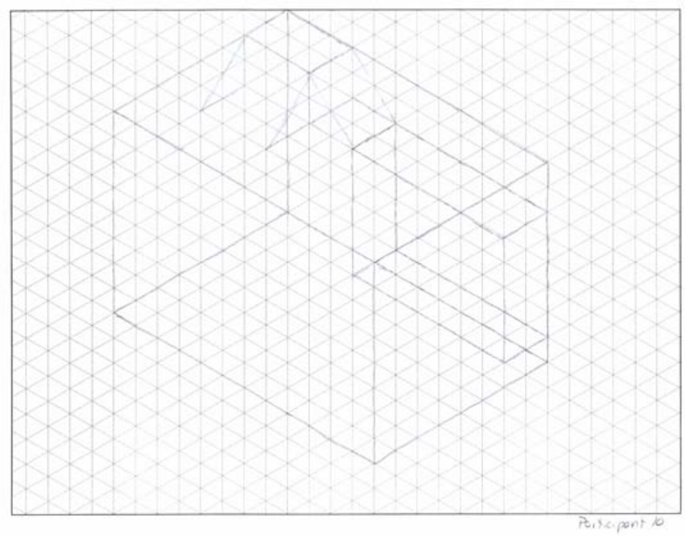

Figure 4.36. P10 ran out of time while trying to complete problem 3.

4.4.5.7.4. P10: Summative Questions

P10 reported that he definitely thought the last problem was the most difficult of the three. He also said that he thought it was easier to do the multiviews than the pictorial. He explained:

> I think the reason it is easier to go from the 3D to the multiviews is because you've already got all the pieces put together. When you're trying to work from multiviews, put that into 3D, it, it's, you've got to, in your head, see what that 3D shape is, [see what the] 3D object's going to be before you can get a sketch down.

P10 admitted that spatial problems are somewhat frustrating at first:

> ...these are...challenging but accomplishable. Um, it's a little frustrating at first just trying to look at it...just trying to figure out, looking at that multiview, just in my head, see what the shape, what the actual 3D object's going to look like. That was kind of difficult.

At the end of the interview, I provided P10 with a technique for centering his pictorial drawings on the page. I also encouraged him to double-check his sketches to make sure he did not make small errors.

4.4.5.8. Participant 10 Structural Description

P10 did not seem to have significant difficulty with the three problems, even though he initially was unsure that he would be able to do them. While he may not have been able to visualize the totality of the latter two objects initially, he was able to work his way through the problems systematically without letting himself get frustrated. Although he did not complete the last problem, I believe he would have given more time.

4.4.5.9. Participant 11 Textural Description

4.4.5.9.1. P11: Problem 1

When given the first problem, P11 did not take much time to examine the pictorial. Almost immediately, he began drawing the construction box for the front view. He then drew the positive geometry and then the negative geometry. He then created the right side view and top view in a similar fashion, as shown in Figure 4.37.

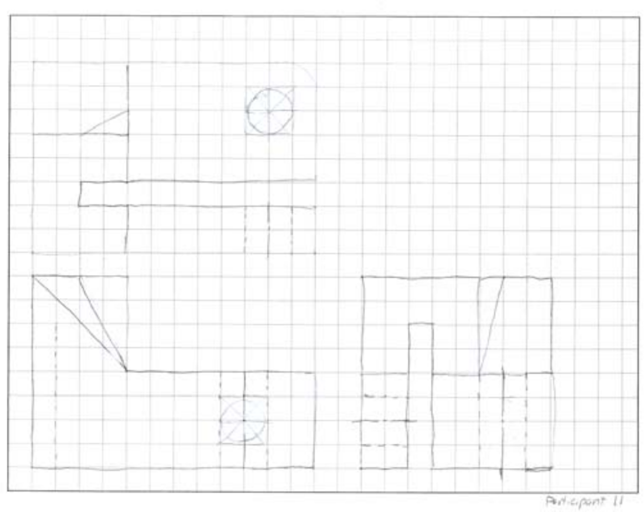

Figure 4.37. Except for the misaligned holes in the front view, P11 was able to complete problem 1 successfully.

4.4.5.9.2. P11: Problem 2

As he started problem 2, P11 again did not take much time studying the object. Instead, he drew the construction box and started drawing the multiviews on it. After he spent a lot of time pondering the object, I realized that he would be unable to complete the entire object. I stopped him and gave him a simpler object. Figure 4.38 shows what he had drawn for problem 2.

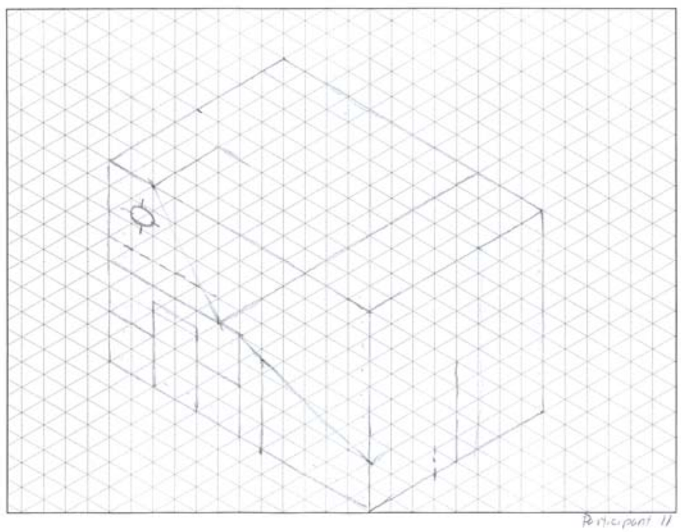

Figure 4.38. P11 tried to solve problem 2 by placing the multiviews on the isometric construction box.

The next problem P11 attempted to solve was alternative A (the upper, U-shape of problem 2). As he started to draw this second object, it was apparent that he was remembering problem 2. As shown in Figure 4.39, he drew the profile from problem 2 on the new problem. For whatever reason, it seemed he was stuck on this particular facet of the problem. I let him draw for a few moments, but again he stopped and did not seem to know what to do next. I decided to give him alternative B (since it appeared he was not picturing that part of the object).

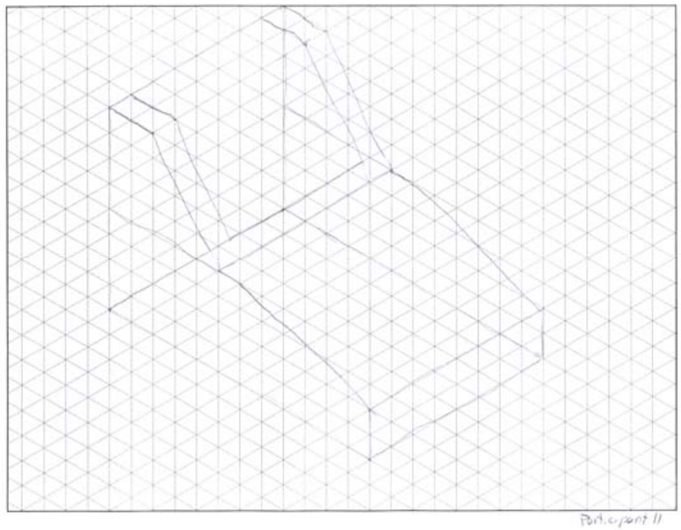

Figure 4.39. P11 tried to draw alternative A but was unable to do so.

When P11 started working on alternative B, it became quickly apparent that he was having significant difficulty visualizing the pictorials. As shown in Figure 4.40, he oriented the object in the wrong direction, although he said he was able to picture the overall shape of the object. Once he had drawn what is shown in Figure 4.40, he stopped and said that he was done.

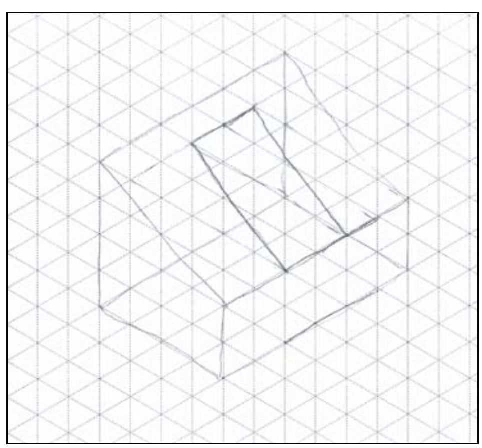

Figure 4.40. P11 was unable to orient or draw alternative B correctly.

4.4.5.9.3. P11: Summative Questions

When I asked, P11 said he thought the multiviews were easier to do. He said they were easier because, "you know the whole 3D object and you know where everything is supposed to go. So you are just kind of asking yourself, what would it look like from this view, as opposed to trying to get a view and put it together." I asked P11 how it felt to be posed with spatial problems. He admitted that it was frustrating for him to visualize.

At the end of the interview, I spent a significant amount of time with P11 on the process for developing pictorial views from multiviews. I went through two other problems (unrelated to the study) in an effort to help him understand how to create them. We also spent a small amount of time discussing the errors he made on the multiview drawing in problem 1.

4.4.5.10. Participant 11 Structural Description

Of the participants in the study, P11 seemed to be the most lacking in spatial ability. While other participants were unsuccessful with problem 2, most were able to do simplified portions of it, whereas P11 was not. It was very difficult to understand what he was thinking because he was very brief and did not provide a lot of detail about what he could or could not see. Additionally, he seemed somewhat aloof or uninterested in the subject matter. Nevertheless, I took the time to provide instruction at the end of the interview.

4.4.5.11. Participant 12 Textural Description

P12 acknowledged that she was unsure of what to expect concerning the applied problems in the second interview. She communicated:

> I just wasn't quite sure what you meant by applied problems, math problems or more like sketching problems. Sketching is a thing that kind of gets me in CGT just like, because they are picky for a reason, lines too dark, lines too light and stuff like that, but I guess it’s good cause our exam is like in two weeks from now, on Monday after Spring Break.

4.4.5.11.1. P12: Problem 1

P12 started problem 1 by creating construction boxes for all of the multiviews. She began with the positive geometry of the object and then moved on to the top view, doing all the positive geometry there. Finally, she did the positive geometry in the right side view. To complete the drawing she did the negative geometry. However, she forgot her negative geometry in the front view, as shown in Figure 4.41. Nevertheless, she did do a final visual check over the entire drawing before saying she was done.

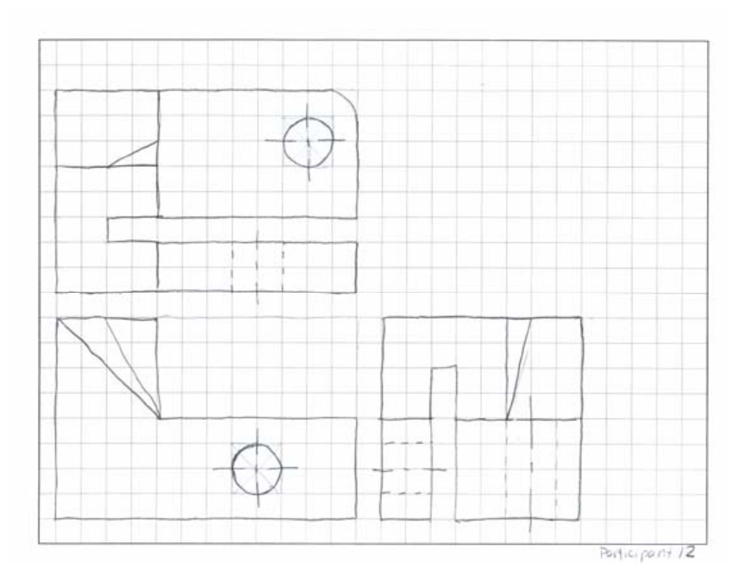

Figure 4.41. Although her front view was missing hidden lines, P12 was able to create the multiviews for problem 1.

4.4.5.11.2. P12: Problem 2

After I showed P12 problem 2 her immediate response was:

> Oh, crap. Ok. Um, first, I would kind of see how it all fits together, I kind of fold the top and side view kind of like a box in my head. Do I have get a pass card?

I asked her, "Can you see the object in your head? Or portions of the object?" She responded, "I can tell that...I am going to have two holes going through the top prong-looking things. And then this surface is back compared to this front surface." She then drew an isometric box to start the pictorial. Yet, as shown in Figure 4.42, P12 started drawing the multiviews on the faces of the box. Although I let her continue this for a few minutes, I could tell she was frustrated and would likely not be able complete the drawing. Therefore, I stopped her.

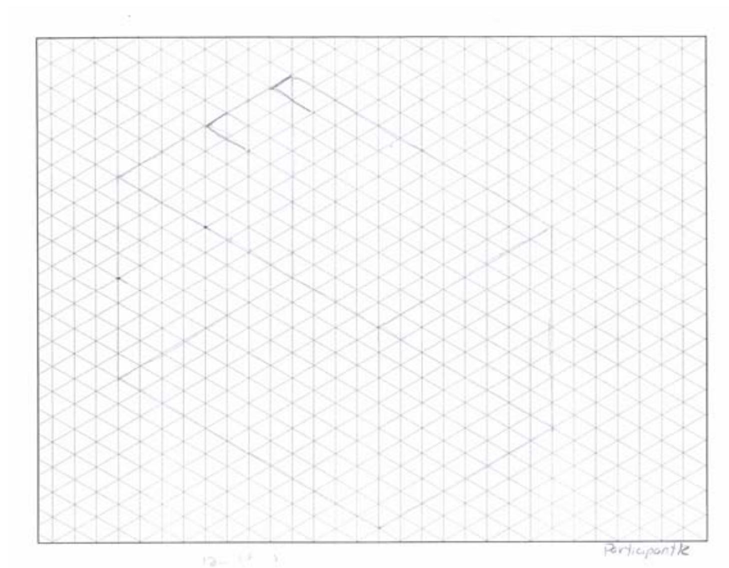

Figure 4.42. P12 began solving problem 2 by placing the multiviews on the isometric construction box.

After stopping P12, I had her do alternative A because she said she could see what it looked like. She was able to complete the object quickly. She started with an isometric box to contain the object and then created two top planes, which are coplanar with the top of the box. However, she had some difficulty with defining the depth of the slot, as shown in Figure 4.43.

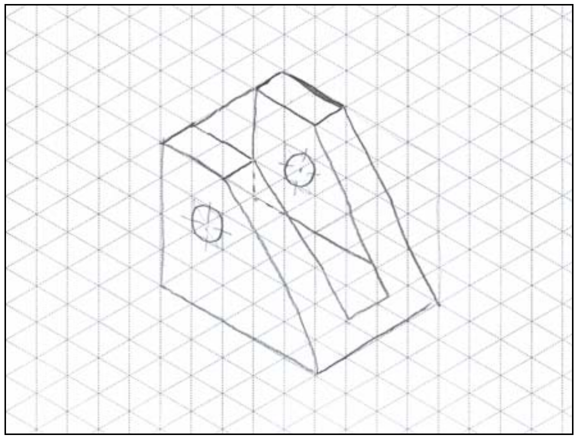

Figure 4.43. P12 was able to solve alternative A correctly except for the depth of the slot.

4.4.5.11.3. P12: Summative Questions

After she completed alternative A, P12 acknowledged that pictorials are much harder for her to do. She admitted:

> Pictorials. I think with me, um, I get frustrated easily. So when I have three views and I have to like put them together, sometimes I get overwhelmed a little bit. That is why when you had this one [alternative A] I could just focus on just that part and then I could get it. But when I have that part and other parts that I have to worry about, I kind of get lost in my mind and everything else, which is why I get confused. As I said, I didn't know where to start. Like in class, when we do them they are a little bit, depending on which one, it’s easier cause you have really big holes somewhere and like ok, I can start with holes and work my way around. But with this one [problem 2], I had a hard time like, figuring where everything was supposed to go. And like making it in my mind and putting it on paper.

I asked P12 if she was able to visualize parts of problem 2. She acknowledged:

> It was pretty much like I’d think I knew a piece, but I really didn't know how to like, I could kind of tell how this was supposed to look, but I couldn't figure out how to draw it relative to everything else. Cause I knew there was another surface coming out, so I didn't know how that was going to affect this and then I knew there was this part in front of it. I was just kind of getting confused and frustrated. I am the kind of person when I get frustrated, sometimes I shut down and it’s like I can't, I can't break it. I run into it a lot. It’s happened quite a few times.

P12 described that her coping mechanism with difficult problems is to work on them a little bit at a time. P12 said, "Something like that I can visualize a little bit easier...I noticed this a couple times like last year too when I would get problems like this, I would just kind of like freak out and not know where to start. And, that's kind of like the biggest thing is not knowing where to start. Like once I get started, I can like, work my way through it."

After we concluded the interview, I taught P12 a method she could use to create pictorial drawings. I told her to break the problem down, focus on pieces, and do not let yourself get frustrated by not being able to visualize the whole thing all at once. We then focused on the pictorial creation method. I also told her how to center her problems on the page. Before we finished, we discussed problem 1, and that she needed to ensure she didn't forget simple things.

4.4.5.12. Participant 12 Structural Description

Although P12 was able to complete the multiviews, she had significant difficulty with pictorials. It seemed that she had difficulty being able to break a problem down into manageable chunks and finding a place to start. She acknowledged that frustration is a difficult thing for her. Once she gets to a certain point, her frustration makes it impossible for her to get work done. Nevertheless, P12 was able to solve a simpler pictorial problem.

4.4.6. Second Interview Summary

The second interview was very revealing and valuable. Through it started to emerge several similar characteristics in the ways in which high and low ability participants solve problems. Ways of thinking, approaches to problems, and understandings of the course material seemed to be consistent among high and low ability learners—not in every degree or manner, but enough for me to start noticing patterns or similarities between them. Apparent also were the range of emotions associated with students who are learning a new subject or skill and how they grapple with their own learning. It was interesting to find that the feelings of frustration, confusion, and intimidation were not limited to one group or the other. In fact, all participants had these feelings at various times and to various degrees. The extent of these feelings varied across ability level.

In a more practical way, through the applied tasks it was evident that the course was doing a good job of providing both skill and a process for the generation of multiviews from a 3D object. All of the students, regardless of ability level, were able to do the basic multiviews in problem 1. Granted some made simple errors—a forgotten or added line, missing hidden lines, and the like—but generally they were all able to create the required multiviews.

However, the creation of pictorials was quite a different matter. It was during one of the "instructional moments" with the second or third low ability participant that I realized that I was saying the same thing, repeatedly, to the participants who could not solve the second pictorial problem. It was at that moment that I realized (1) I was using a process for pictorial creation, (2) the high ability students also were using a similar process (often unbeknownst to them), and (3) the low ability students were not using any process. This was likely the biggest "ah-ha" moment during this study.

The second interview also revealed common problems or errors made by various ability groups. For example, often when a participant was unsure how to start the pictorial, he or she would start drawing the multiviews on the faces of the isometric box—likely trying to "work it out on paper" because it could not be seen in the mind. Similarly, in regards to the pictorial views, all participants had difficulty orienting the object on the paper at the beginning so that it would fit properly.

All of these items were emergent during the second interview. Taken alone they are but intriguing, but when combined with data from the first interview, the third interview, and other data sources, they go beyond intrigue and become more relevant as findings within this study. While the next chapter will tie these emergent threads together, the next section will examine the data revealed in the third and last interview with the participants.

4.5. Data from the Third Interview

The third interview was designed as a summative interview to garner final participant thoughts towards spatial ability. Table 4.6 shows the order of the third set of interviews. At the time of the third interview, students were over two-thirds of the way through the course and had a unique perspective, looking back to the beginning of the course. The questions posed in the third interview were aimed at garnering participant thoughts concerning the sketching exam from the course, spatial ability, and the course and study. This section begins with the fourth epoché session that I conducted immediately after the third epoché session. It then provides the data as communicated by the participants in the third interview.

Table 4.6.

The Order of the Participants in Interview 3.

Order	Participant	Order	Participant	Order	Participant
1	P01	5	P11	9	P04
2	P05	6	P02	10	P03
3	P07	7	P10	11	P12
4	P06	8	P09	12	P08

4.5.1. Researcher Epoché from the Third Interview

Concerning how I would describe the creation of multiviews to someone who knows nothing about it, I wrote:

> Extracting multiviews from a pictorial requires that you imagine yourself walking around the object or holding the object in your hand and rotating

> it. In either case, a multiview is nothing more than a straight-on view of one side of the object. Where visible edges are, lines are drawn. Where non-visible features of the object occur, such as a hidden hole or slot, dashed lines are drawn. Where hidden edges are occluded by solid lines, they are not represented.
>
> Typically multiview drawings include however many views are necessary to adequately represent the object—usually three are required, top, front, and right side. The frontal view is typically the view that is most descriptive of the object.

As I thought about whether I used a process for multiview creation, I admitted:

> I cannot say that I have a particular process I go through. Often I feel like it is part dependent and that I vary my approach depending on the features of the object. However, I do tend to sketch out the construction boxes for all the necessary views as a starting point, and I typically begin by drawing the front view. Aside from that, my process is highly dependent upon the object.

In response to what I would recommend to individuals having difficulty with multiview drawing, I acknowledged:

> Probably the best advice I could give would be to begin by taking physical, tangible objects and simply looking at them. Cut blocks are best, but if you do not have access to those, you could use anything that can be physically manipulated with the hands. With these objects try viewing and imagining what the multiviews would look like. Once you have practiced this, the next best thing is to draw some sample drawings or do some exercises that allow you to practice creating multiviews. The key is to start with simple objects first and build up to more complex ones.

To explain pictorial drawing to someone who does not know how to do it, I said:

> Describing this is much more difficult. To be able to create the pictorial you must first understand how multiview drawings work and the rules associated with them. Given this knowledge, you try to look across the views presented and picture the object in your mind. For me, the rest just happens and I am not quite sure why.

Pondering whether I used a process for pictorial drawing, I noted:

> For the most part, I almost always start with a general box. Then I either cut away parts of the box, or add basic primitives to it, depending on the pictorial I am trying to create. Aside from that, like doing multiviews, I believe it is somewhat part dependent.

Thinking about advice I might give, I had a hard time recommending things to improve pictorial creation:

> Advice on this one is much more difficult. Really the only thing I have found that helps is practice actually doing pictorials—starting with simple objects and building up to more complex ones.

When asked how I feel about solving spatial problems, I revealed:

> Actually, I enjoy trying to visualize objects. Seldom do I get frustrated or aggravated with doing spatial problems. I really enjoy trying to picture things in my mind and then manipulating them.

4.5.2. Third Interview with the High Visualization Group

The following sections provide the textural and structural descriptions for each of the high visualization interviewees.

4.5.2.1. Participant 1 Textural Description

P01 believed that she improved her spatial ability in the course. She said:

> I think cause like at the beginning of the semester like, the isometric drawings especially were more difficult like, and even when we did some of the more complicated multiview drawings like, I was just kind of confused and I don't know, it seems a lot easier now, and it doesn't take me as long to sit and think about it before I draw.

I went on to ask P01 to describe multiview drawing. P01 described the creation of multiview drawing using the box analogy. She said:

> ...take a box and put the object in a box and then pull off each side of a piece...like you move the object and you just like, "Oh, that's what that side would look like," and then you like, move the object again or you are moving yourself around the object, "that's what the right side would look like." That's what the top would look like.

P01 described how she created multiviews. She said, "I like look at it, basically turn it around in...my head and be like, ok that’s...what just this side would look like." P01 recommended that if someone was having difficulty with multiviews that he or she use the labeling technique because it helped her. The labeling technique shown in the course encourages labeling points on surfaces in the pictorial and multiviews to help find the planes in various views.

P01 also described the process of generating the pictorial view. She said:

> Take [it] piece by piece...first I usually look at the most descriptive side and then, try and figure out like how big the object is first, and the basic like, basic shape of it...and then how all the ellipses and other pieces try and connect by looking at the other views.

P01 acknowledged using a process for creating pictorials. She said that she drew the isometric box (to contain the object) and then looked for features that were coplanar with the edges of the box. She recounted:

> Basically, I draw the pieces on the end first and then I'd usually take like, um, like, last night on the test it was ah, like depending on how thick it is draw the next thing on thick it is, like right behind it.

P01 reported that when she was doing a pictorial she "constantly looks across the views." She also said that she had to "focus in on little pieces" of the object, rather than the whole. For her, most if it did not "all come together" until she had most of it done.

P01 acknowledged that spatial ability problems "don’t like stress me out or anything." On the contrary, P01 said that she enjoyed using her spatial ability. She said, "I think it’s like cool how you can take a picture and just like...make multiviews of it or make the isometric sketch of it." P01 felt confident that given enough time she could figure out most spatial problems. P01 said she thought that sketching and mentored sketching in the course were very important to developing spatial skill.

4.5.2.2. Participant 1 Structural Description

P01 believed she improved her spatial ability because she could visualize more quickly. She enjoyed exercising her spatial ability and did not find the problems stressful. P01 was able to provide a description in her own words of both multiview and pictorial creation. She said that the mentored sketching in the course was the most beneficial in developing her spatial ability.

4.5.2.3. Participant 2 Textural Description

When asked, P02 was unsure whether his spatial ability had improved in the course. He admitted:

> I'm not sure. I've not really thought about that. I mean, I guess more practice and doing it more can't hurt you. So, I guess yes, it has improved. But...I felt like I was reasonably strong coming in, but I mean, like I said, more exposure and experience can't, can't make you worse so I, mean I guess, I guess...it just...sort of changed some ways that I look at things...just different procedures and theories about how to go about looking at an object. I mean in, I had my own way of doing things and now other, I don't know, other procedures I guess for like looking at a three dimensional object and how to break it down.

P02 described multiview creation as, "how you want to draw the object as you would see it from different ways...basically consider yourself here and your looking forward and you only see the front...you know, how surfaces and lines would look when you're looking at them from that 90 degree angle." P02 felt like he had a subconscious process for creating multiviews, "...subconsciously you like see an object and then like, ok, draw it from this view and you just immediately, just start processing."

P02 said he felt that visualization was second nature and did not take a lot of effort. "It’s not a lot of like real churning going on. I mean, sometimes when you get to a difficult feature or something, you have to sit there and contemplate it a little bit, but I mean if somebody says...think of this object from the front view, I just look at the object and I immediately start seeing the front view," he admitted. P02 acknowledged that the most important things in learning to do multiviews are "practice," "taking your time," and "not getting frustrated."

Describing pictorial creation was a little harder for P02. He said that it’s "a little more difficult...I don’t know, that’s tough." As for his own process for creating pictorials, P02 highlighted that it was important to look across views, "You have to be continuously relating to all three of them [views] so you know what it looks like. I mean, there are three views. It’s a three dimensional object. If you just work off one...I think you might have some discrepancies and it might not look correct." P02 revealed that while he may have a process he used, he did not "really think about it. I just start and work it out."

P02 thought that it was important to practice multiview creation to get better at pictorial creation. He stated, "I mean, I think that would develop them [practice in multiview creation] because you would see how it breaks down and you'd be able to assemble it back up easier."

P02’s feelings towards spatial problems were positive. He said he thought they were "kind of neat and they’re kind of fun to work." He did not think they were difficult and they did not stress him out. P02 believed that the mentored sketches in the course were very helpful to student spatial development.

At the end of the interview, P02 acknowledged that he felt very confident after doing the exercises in interview 2. He said he thought, "It helped gauge, sort of, where I was."

4.5.2.4. Participant 2 Structural Description

P02 was very confident in his ability to do spatial problems. He seldom had difficulty with the spatial problems in the course or study. He said that most of them were fun, challenging, and he enjoyed doing them. While P02 was able to describe multiview creation verbally, he could not put into words the process of creating pictorials. He recommended that practice, particularly practicing multiview creation, was highly important. He admitted the importance of not getting frustrated in the visualization process.

4.5.2.5. Participant 3 Textural Description

P03 stated that he thought the course had helped his visualization skills a lot. He said, "I find it easier to visualize, and easier to draw...I can tell it has gotten a lot easier to look at pictures" and visualize them. P03 described the transformation that occurred to him during the course by saying, "I can remember the first day, I saw a bunch of lines. Until like the end of class and then it all came a lot clearer."

P03 said he was not quite sure how to describe "interpreting multiviews" verbally. However, he said he did adopt the process of multiview creation that was described in the course. P03 said that sometimes he would shade-in surfaces on the pictorial to understand how it might look in the multiview drawings better. He also said he looked across views quite a bit as he was working.

P03 reported that when creating a pictorial, the front view is the most important to him. He said that he started visualizing the pictorial by imagining the front view, and then connecting the top view and right side view to see what it was like in the front view. He said his process for actually drawing it was similar.

When asked how he felt about spatial problems, P03 stated that he was more confident about doing drawings and that he found it interesting. He noted:

> If I was posed with some of these questions earlier, I would probably be like, I would find it pretty difficult. But, I mean, I might still be able to pull it off, but then again I'd probably still forget centerlines... [but] I would have to say it was pretty interesting. I did like doing all the sketches and stuff. So...it was pretty interesting.

P03 said that taking the multiviews to the three dimensional pictorial was the biggest help to his spatial ability in the course. He also thought that the sketch exercises in interview 2 helped him prepare for the exam.

4.5.2.6. Participant 3 Structural Description

By his own admission, P03 had significant difficulty in the beginning of the course, "seeing only lines" from the drawings. However, over time he had significantly improved and actually enjoyed developing and exercising his spatial ability. While he had difficulty putting into words the description of multiview and pictorial drawing, he said that he did feel like he had a process for doing both. During the semester, his confidence in doing spatial problems increased greatly and he could visualize and draw better because of it.

4.5.2.7. Participant 4 Textural Description

P04 began interview 3 acknowledging that she had significant difficulty with the sketching exam. She said she thought it was hard and that she was really pressed for time. P04 acknowledged that she thought she considered her "spatial ability to be greater than it really actually" was. She said she felt humbled. Nevertheless, P04 acknowledged that she felt like she had learned a lot through the course.

P04 described the creation of multiviews as imagining "that you can only see one side of it [an object] and you try to imagine what that side of it would look like." P04 said that for multiview creation, she used the process described in the class. She suggested that using physical objects could be helpful in visualizing because that was what she had done at times.

P04 was unable to describe the creation of pictorial drawings. She said, "It is hard. It's hard to just to do it period. I think it's harder than going the first direction." She said that she would likely describe it the way I had described it to her during our instructional session at the end of interview 2. However, she said that the process did not help her on the exam. She said she thought her process for creating pictorials was part dependent:

> I think it is part dependent, but mostly I just try to just, I tried originally to just draw the big box that you showed me, but if that kind a doesn't work out, then I got to like individual pieces of it. But I try to at least, once I have a box there, to do anything that’s easy and get that done. And then worry about the more detailed pieces of it.

P04 said that she was intrigued by exercising her spatial ability. She said, "It was challenging, and sometimes very difficult, but I liked it." P04 said that the isometric sketches were the most challenging thing for her and that the exercises in interview 2 were "excellent practice"; she "definitely learned a lot from that."

4.5.2.8. <u>Participant 4 Structural Description</u>

During interview 3, P04 was in a humbled state; she had just done poorly on the sketching exam. Nevertheless, she thought that she had improved her spatial ability and learned much from the course. While she could verbalize the creation of multiview drawings, she found it difficult to describe the creation of pictorial drawings. P04 acknowledged that while she found exercising her spatial ability challenging and difficult, she really liked it.

4.5.2.9. <u>Participant 5 Textural Description</u>

P05 did not think her spatial ability improved due to the course. Rather she felt more confused after the class. She said that because of confusion with the terminology, she was unsure what the teachers were looking for. Therefore, she did not think the course improved her spatial ability.

P05 described the creation of multiviews as "taking that object and if you want the front view, you will look at just the front of the object and visualize, smush it flat, and then drawing just where there was going to be lines." Of the process she used for creating multiviews, she said she always did the view construction box.

P05 explained the creation of the pictorial as:

> ...a little more complicated to explain...it's kind of the reverse process...I always start with the front view and see what I can get...and then do a quick look over at the top and right view to try to get an idea of the picture...You got to try to get an overall big picture of what the outside of the object looks like first, and then you can fill in little pieces.

She said that when she did a pictorial drawing she would look across views a lot. She acknowledged:

> Not constantly, but, but like I said, I'll always look at the front view first. You can't, you can only get so much from one view, that's why it's a multiview. So, you have to keep looking over at others to try to figure out piece by piece, "Ok this piece is going, based on this, this piece comes out based on this, this piece, you know looks like this." Um, yeah, I mean I have, I can't focus on all of them at the same time. But you have to utilize the other two to understand one.

P05 relayed that how she felt about spatial problems depended on the day, and how she felt. She said, "Sometimes it's like, yeah I get to figure something out, or dang it I have another thing to do." P05 said she did not necessarily find doing spatial problems that interesting. She said:

> I mean it's, it's kind of interesting but at the same it doesn't feel like I'm really solving anything. It's just another interpretation. I'm saying, 'Yes, that is what it is and here's another way to represent that same object, so...' I mean, it's all right. I like figuring out the problems but, I feel like, I definitely feel more constructive doing other things.

P05 thought that working in the software was more beneficial than the sketching exercises. Additionally, she stated that involvement in the study was insightful into the way she approached problems. She said:

> Insightful. Yes. Like I said, I really don't like think about the way that I solve problems. I mean, that was interesting because, now that I have discovered that through this process [the study], um, it makes me think

> about problems a little different and acknowledge that, since this is pretty much how I do things all the time, if I am running into troubles using that then I should use something else, that I should do it a different way. Little things like that have helped me.

P05 stated that the problems from interview 2 were helpful. She said they were "more complicated than anything I'd seen in a while, so it kind of made for a good refresher."

4.5.2.10. Participant 5 Structural Description

P05 seemed indifferent to what she had learned over the course of the semester. She did not think she had improved her spatial ability in the course. While she could provide verbal descriptions of the creation of multiviews and pictorials, she said she did not find it that interesting because it was not creating anything new. Her feelings toward spatial problems vary, but she did find participation in the study insightful and the problems in interview 2 helpful.

4.5.2.11. Participant 6 Textural Description

P06 said that the course had helped his spatial ability a lot. He said:

> ...the spatial sketching, like I'd been doing that stuff before I came to school. We've done that in a couple of my classes, we didn't have to sketch, but I really had difficulty. But once I was taking the class and they really broke apart how to do it right, and how to think about it, then it really helped.

P06 acknowledged the importance of spatial ability and sketching. He admitted:

> ...now ideas coming, are becoming more, you know, easier to put down on paper and things like that so I can definitely see a lot of use in the industry when you know, we're called to come up with designs and, you know, have to present it. If you can draw it out it's better than just describing it, so, I can really see it helping.

P06 described how he thought about the creation of multiview drawings from pictorials. He described:

> I just try to mentally take the object, whatever it is, and then just flip it, so that all I can see is the one side I'm supposed to be drawing in the multiview...I just think about it as a 3D object...you're just looking at it straight-on, dead-on, one side and draw what you're seeing from there. So that's usually how I try to think about it to draw the multiview.

P06 acknowledged that he usually began a multiview drawing with the front view because "you can usually see that." However, from there he said that his process was "a little problem dependent...kind of...set in stone, but not really."

P06 said that when you are creating a pictorial drawing you "always try to break it up" into visually manageable chunks. He explained:

> I think the main problem...is you're trying to look at the entire piece all at once [however] when you're looking at everything, it's kind of, it's easy to get real messed up. But if you break it apart into easier sections, and easier blocks, and you know, break it up [into] three, four, [or] five different parts, then...it's easier to visualize each of the parts and then it's easier to put them all together and it's easier to just kind of think of the entire thing in one piece."

To create pictorial views, P06 recommended using one view as a "base view" when you are creating multiviews. He advised:

> Pick your base view and then from there, build on the other parts of it. Because if you're trying to use two or three different views as you know, as kind of the base view, you'll screw it up really easy. But if you kind of use one view as like your, this is set in stone, I'm going to think about everything from this one view, and then you build onto that view, and you build from this...then it's a little...easier to construct it in your head...

P06 said initially he was pretty nervous about the class. He admitted:

> I kind of freaked out because I've never been very strong in anything that had drawing. But once I started getting into it, like now I like, I mean I don't know if it's the right term that I enjoy to do it because it's homework, but it's definitely one of the more interesting classes I'm in so, I do enjoy doing

> this stuff and I do enjoy the challenges it presents. It’s a very interesting class.

P06 said he felt confident about his abilities. Concerning the extra credit problem that students could do instead of participating in the study, he said:

> ...I remember that big 50 foot problem that they gave at the beginning...but I’ve looked back at it now and it really doesn't look as bad anymore...once you start breaking up things and doing some of the techniques...it really isn’t that bad.

P06 said he initially felt pretty frustrated with spatial thinking. He said, "So I was having some trouble with some of the earlier stuff and it was real frustrating, but you know, once you got into the swing of the mindset for this stuff it really wasn’t that bad." He said that he thought the mentored sketches in the course, as well as the work in the software, were the most helpful in developing spatial ability.

4.5.2.12. Participant 6 Structural Description

P06 addressed his initial concern and anxiety with the course. He reported that for a while he struggled with understanding how to visualize and draw. However, over time and with practice it started to make sense to him and he thought he had improved his spatial skills significantly though the course. P06 was able to describe the process of creating multiviews and pictorials verbally. He also said that he had a process that he used. P06 made several recommendations as well.

4.5.3. Third Interview with the Low Visualization Group

The following sections provide the textural and structural descriptions for each of the low visualization interviewees.

4.5.3.1. Participant 7 Textural Description

When asked about the sketching exam, P07 said that she thought she did better on the exam because of participation in the study. She said she thought the exam was a moderate exam.

P07 said that she felt like she had improved her spatial ability and that the process I showed her for creating pictorials helped her. She said:

> ...that whole thing...you explained to me about the planes actually touch...that helped me so much because before...when I pictured it I couldn't...decipher between the ones that were like flat up against it and the ones that were pushed back and it kind of got jumbled in my head...that just made it a lot clearer.

P07 also said the course had made her better because it encouraged her to visualize before drawing.

P07 described the creation of multiviews as trying "to break...down each view, cause that's basically what you are doing. You are breaking it down and looking at...what planes fall...where they fall, and where they connect to try to get a 3D image in your head." P07 said that her process for creating multiviews was partially "dependent on the object" but that she did use the process described in the course. Although she described multiview creation, P07 had difficulty putting pictorial creation into words.

P07 said that at the beginning of the course she felt "overwhelmed" when posed with spatial problems. However, after the course she was a little more confident. She felt:

> ...a little bit more confident cause I kind of, like, I've done it before, so I'm getting a feel for what I need to do. But when I first started I was like, I don't know, didn't think and just went into it the best I could. Just with no kind of like, plan or strategy to attack it. At least now I kind of know where to go.

While she said she had a lot to work on and that she was getting better, she enjoyed exercising her spatial ability. Yet, P07 still felt somewhat limited in her ability to do difficult problems. She said, "I could probably figure out some of it, but no, probably not like a big thing."

P07 said that the grid matching exercises that they were required to do at the beginning of the semester really helped. She also thought that the mentored sketches were vital. And, although P07 said she was really "embarrassed" in interview 2 when she "couldn’t figure out" the sketches, she said the sketches helped her a lot and helped her "realize what I need to do to get better."

4.5.3.2. Participant 07 Structural Description

P07 recognized that, while she still had a lot to learn, she had improved her spatial ability through the course. She acknowledged also that she had enjoyed the course. P07 was able to describe the creation of multiviews verbally, but was unable to put the creation if pictorials into words. She also stated that the process I showed her in interview 2 was very helpful in the creation of pictorials. Prior to the interview, she was unsure how to create them.

4.5.3.3. Participant 8 Textural Description

P08 stated that he did not do well on the sketching exam and that he found it difficult due to the technical drawing standards. P08 did not believe the course helped his spatial ability. He did not think he could "improve so fast." P08 described the extraction of multiviews as "see it as one-dimensional...just look at what you see on the surface." He went on to say he could show it more easily than describing it. P08 believed his process for doing multiviews was dependent on the part being drawn. He also stated that he found the technical drawing activities in the course uninteresting. P08 believed that visualization and sketching were more difficult at the end of the course than when he first started.

4.5.3.4. Participant 8 Structural Description

P08 communicated that he did not have a successful semester in the course. Overall, he did not believe that the course had improved his spatial ability and he found the sketching and other assignments uninteresting. As with prior interviews, the language barrier kept the interview short and to the point, but it seemed obvious that P08 had encountered much frustration in trying to do the course exercises and in improving his spatial ability.

4.5.3.5. Participant 9 Textural Description

P09 stated that she thought the sketch exam was "all right." She stated that it took her "a little bit longer than other people," but she "finally got it to work and kind it kind of made sense." She said it was like, "Oh, I can see!"

P09 said she thought she had improved her visualization ability in the course. She reported:

> I do think I have [improved]...greatly especially since the first week like, I had absolutely no idea what was going on but, you expect me to do what? You know I really didn't understand, but now I think I've got a pretty good handle on it.

When asked to describe multiview creation, P09 said that she would have to describe it by showing it rather than explaining it with words. However, later she described it as, "kind of turn it around in your mind, and try and see just one face of it instead of the whole. Kind of make it flat." Nevertheless, she did feel like she developed a process for developing multiviews; she used the process described in the course.

When asked about describing pictorial creation, P09 said she was unsure of how to describe it. She said, "I can explain chemistry or I can explain math, but this? This is just something that is hard to explain." Yet, she said she felt more comfortable with spatial problems. She commented:

> I don’t think I’m comfortable enough with it to where I can just look at it and be like, ok I know what I am doing...so I kind of sit and reflect about it a little longer still. But I definitely feel a lot more comfortable with it than I did at the beginning of the course.

P09 said she did have a little bit of anxiety at the beginning of the course. I asked if she thought it had gone away. She responded, "I think it has gotten a lot better after the sketch exam."

P09 issued that she had found learning about spatial ability interesting. She said:

> I think it’s been interesting to see how I’ve progressed over the course. Like you know, I definitely knew at the beginning I didn’t really know what was going on. So now I, I have a good handle on it, but I can still get better. And so, I think it’s been a good course in that I've learned a lot about learning, like just learning something from scratch. So it’s been, it’s been pretty good.

P09 stated that the mentored sketching helped her a lot. She admitted, "Just because you know it’s an example of what you’re going to do for your homework. And, you have somebody going through it with you, step by step mostly. So I think that’s really effective..."

P09 also thought that participation in the study was helpful. She acknowledged:

> I think I kind of understand better what I kind of need to work on and, you know, just being able to talk it out with somebody kind of helps me kind of go through the process and think about, "Well, maybe I haven't been doing this right but I'm, I’m good at doing this part so I just need to focus on the stuff that I don't know how to do." I think this kind of helped point those things out instead of just having just having the class...

P09 said she thought the sketches in interview 2 helped also. She said "I definitely was able to visualize things a little bit better after we sat here and went over what I had to draw so. I think it definitely help me."

4.5.3.6. Participant 9 Structural Description

P09 began the course without an understanding of what was going on. As the semester progressed and she learned how to visualize, she found it to be a positive experience. P09 acknowledged that she still has much room for improvement, but she made significant strides in the course. P09 was able to put into words the process of multiview creation, but not pictorial creation. She said she found the mentored sketches, as well as participation in the study, extremely helpful.

4.5.3.7. Participant 10 Textural Description

P10 began by saying that he thought he had improved his spatial ability through the course. Because he was in aviation technology, he could see how visualization would be needed to understand blueprints and drawings.

P10 described the creation of multiviews as imagining "the object in a box and then ah, just look at it from the different directions of the box, look at, at it straight on." While he used the process described in the course, P10 said his process for creating multiviews was part dependent.

P10 said that it was "a little more challenging to describe to someone" how to develop pictorials. He said, "I would say just look at the multiview drawing. First of all you would have to know which side is which...I'd tell them which view was which side of the part, and then try to visualize how it would fit together." Similar to multiview creation, P10 said his process for pictorials was also part dependent. Yet, when creating pictorials, P10 recommended looking for the "simplest geometry... big basic simple geometries and try to go from there."

P10 communicated how he felt at the end of the course. Having taken the course, P10 said, "I feel a lot more confident that I can actually do it." He said the most frustrating thing was:

> ...just trying to see trying to visualize from a multiview drawing how all the pieces fit together. Sometimes it comes pretty quick, but other times it’s

> just like, if it’s a complicated part, it just takes some time. It takes a lot of looking at.

P10 said he thought that combinations of the mentored and homework sketches helped the most in developing spatial ability in the course. Of the sketches in interview 2, P10 said, "They definitely didn't hurt anything. I don't know that they did any more than our assigned sketches would....no they didn't hurt; just extra practice."

4.5.3.8. Participant 10 Structural Description

P10 acknowledged that he thought he had improved his spatial ability in the course, and he acknowledged a greater confidence in doing spatial problems. P10 was able to provide verbal descriptions of both multiview and pictorial creation, but he said his process for creating both was part dependent. He thought combinations of the sketching assignments and mentored sketches were the most helpful in developing his spatial ability.

4.5.3.9. Participant 11 Textural Description

P11 said he thought he had improved his spatial ability in the course. He said, "I've noticed like I've been viewing objects differently, like, um buildings...you know, how this would look."

P11 described the creation of multiviews as "looking at it [an object] from a certain perspective or angle and it’s just drawing what you would see from that angle." P11 said that he thought his process for developing multiviews was dependent "on what you’re drawing."

P11 described the creation of the pictorial as "like putting together a puzzle or something...you kind of know what shape it’s supposed to be in, and some of the main features, and you just try to put it together in the right spot."

When asked how he felt about spatial problems, P11 said, "I guess at the beginning I was...kind of overwhelmed. It seemed like I really didn't know a lot about, what it we, we're going to be doing and now, I feel a little bit more confident, you know, doing a problem and solve or at least have an idea how to solve it."

P11 said that he thought the mentored sketches were the most helpful because "you can go follow along and use those to help you in the homework." He also thought the sketches in the second interview helped "a little bit."

4.5.3.10. <u>Participant 11 Structural Description</u>

P11 reported that he thought he had improved his spatial ability. He did provide basic descriptions of multiview and pictorial creation verbally. While he said at the beginning of the course he felt "overwhelmed," over the course of the semester he gained greater confidence in knowing how to solve spatial problems.

4.5.3.11. <u>Participant 12 Textural Description</u>

P12 said that she thought that her spatial ability improved "on some things." She said that multiview creation was easier for her than pictorial creation. P12 said that she would describe the process of creating multiviews in an applied way. She explained:

> I would probably try to relate it to something they use everyday, like maybe like a table so we, um, just be like if you stand here and you look at the table, what do you see? And then go...to one of the sides, what'd you see from there? And just kind of like bird's eye view looking down, what do you see? And just kind of like, you know, that's what we draw.

P12 reported that she used the process taught to her in the course for creating the multiviews. She said:

> Like I always start with the ends, with the, I always draw the construction lines, but always start with the edges and then kind of work my way in a little bit, kind of like just what seems easiest for me to pick out like the

> distinct features. I, I find it easier and sometime they'll do like the, they always do the oblique last which I think that's kind of obvious cause it's the hardest thing to do. So they pretty much start with the most obvious stuff more...I do it a little bit differently than they do, but for the most part it's the same method as they do.

Of describing the creation of pictorials, P12 said, "I would probably have a lot of trouble telling them how to do it just because it's something that I find difficult...that I struggle with more than the multiviews." She said the process I showed her was how she would describe it, but the creation of pictorials was what usually frustrated her.

P12 then described the frustration she sometimes felt when dealing with spatial problems. She said:

> I mean I do become very blindsided once I get stuck...I pretty much just kind of give up for a moment and just forget about it. Because once I am frustrated, I know I can't go back and look at it. Cause I am just too frustrated and too upset with the problem...

However, she said that situations like that have happened less, as she had better understood how to do the problems.

In the course of conversation, P12 highlighted that the course did not present a strong process or procedure for the development of pictorials from multiviews. Because of that, she said that the process I showed her for creating pictorials was very helpful. She said:

> ...when you taught me the method for the pictorial views, or going from multiview to the pictorial, I kind of thought, 'Oh, that's how you do it!' Kind of, or it's like, how you can start from like pieces and put them together. I thought that was, I mean, very helpful because I don't think like if I had done that, or if you had taught me that I would, I would still be struggling with them today. So I think it's improving, because it's still difficult for me but it's just like, something like "Ok, now I can take it apart or pull it apart, put it together this way."

4.5.3.12. Participant 12 Structural Description

P12 acknowledged that one of the things she struggled with was frustration. When she did not understand something, she would often "shut-down" and have to come back to the problem later. She acknowledged that events such as that occurred less as the semester progressed. She said she thought she had improved her spatial ability, and she found it somewhat enjoyable learning to visualize. She acknowledged that the pictorial creation process I had shown her was very helpful and gave her a process for doing pictorials.

4.5.4. Third Interview Summary

The third participant interview provided a summation of participant perspectives about spatial ability. In the interview, most of the participants were able to verbalize their conception of spatial ability as exhibited through the creation of multiview and pictorial drawings. Many also provided recommendations that could help when struggling with the creation of drawings. Many were also able to verbalize activities in the course that they believed affected their spatial ability the most. Participant feelings also emerged, with most addressing an increased confidence at the end of the course.

The next section provides the data gathered from the focus group meetings. In this study, the focus groups were used as a way to triangulate data discovered in the participant interviews. While the focus groups were asked questions similar to those posed to the interview participants, the questions were generalized and less directed.

4.6. Data from the Focus Groups

As previously acknowledged, the focus groups were composed of participants with similar MRT scores. Group A was composed of high ability students and Group B was composed of low ability students. Both focus groups were asked a mix of questions from the first and third interviews. Although the initial intent was for none of the participants to know how they scored on the MRT exam, the questions posed to Group A demanded that they have the context of being high visualizers. Thus, at the opening of the focus group meeting for group A, I told them that they scored high on the MRT exam.

4.6.1. Focus Group A Textual Description

To begin the focus group, I inquired what the childhood experiences of the group were; what toys they played with and in what activities they participated. P14 acknowledged that he played with Legos as a child. He said:

> When I was really younger I like put together a lot of building block type of stuff like Legos and they used three dimensional drawings and a lot of times you'd look at that and build something based on, maybe one isometric view, and then you'd have to figure kind of out how it'd look...

P16 also said he played with Legos a lot, but also did a lot of drawing and artwork. P15 acknowledged that she had always felt like a visual person, but did not acknowledge anything particular from her background. P13 acknowledged playing with Legos also.

When asked about favorite courses, all the participants acknowledged math as their favorite. Science, art, and shop were each acknowledged by one person also. P16 acknowledged that he had 3 years of technical drawing before. While he said, "I cannot draw to save my life" and "I have no artistic ability whatsoever," P14 said he was really into "building things and the mechanics about things." On the other hand, P13 attributed her spatial skill to logic. She said that it’s "not really something I was taught. It’s just something I guess, I just have, logic you know?" As for difficulties in coursework, P14 acknowledged difficulty with spelling and grammar, whereas P13 and P15 both acknowledged spelling and grammar as strengths.

Several of the participants acknowledged being involved in sports activities, and that visualization was a part of sports training. P13 acknowledged that she was involved in tennis and that, although she was not taught to do it, she used visualization to better her serve. Alternatively, P14 acknowledged using visualization in swimming. He said:

> Before a race, my coach would tell you like to mentally picture the whole race from start to finish... he would say from start to finish start to picture the whole thing and just, I guess it'd help by calming your nerves and things along those lines.

While she was not involved in sports, P15 reported that she had a visual memory and that it helped her on exams. She said:

> ...whenever I take exams...I usually remember what I write down and it's just like a mental picture of what I write down sticks in my head, or like, I'm, when it comes to charts and graphs and stuff, I remember those more than I remember someone just telling me something.

Many of the other participants also acknowledged being more "visually-oriented" in the learning styles also.

I then asked the participants to describe the creation of multiviews. P13 said:

> ...just looking at an object, from a different point of views, like front, like if you look at it straight on from the front, like what does it look like, like you can't see other sides and just drawing the pieces you can see right there and moving on to the top or the side view.

P15 described it as:

> Just take the object and look at it directly from the front, and draw only what you see just looking directly at it.

P16 explained:

> ...you imagine yourself looking at it from the like a straight on parallel like, straight on angle, and you draw whatever features you see first and then work your way back.

P14 added:

> ...what you do is look at each of the three faces and what you would see when projecting straight onto that face and how you would see it as if you only saw it in two dimensional as opposed to a three dimensional view.

Interestingly, P13 and P14 imagined rotating the object when creating multiviews, whereas P15 and P16 imagined walking around the object when creating multiviews. When creating multiviews, P14 stated that he often looked for the easiest features to draw, and completed features in all views before going on to the next feature. In contrast, P13, P15, and P16 reported that they finish a complete view before moving on to the next view. Nevertheless, all the participants noted that they check themselves across the views a lot when they create a multiview drawing.

I then asked the participants to describe the creation of pictorials. P14 expounded:

> ...you're given what each side looks like when looking head on to it... first I would look at the dimensions of each side and draw out the dimensions of the box, of what it is concealed into it and then, try to draw its perimeter of the 3D model, and the outside, and then try to work on negative geometry afterwards...that would only be noticeable once you got a lot of it put together.

P16 responded:

> Um, you start with like he said, you have a certain set area that's going to contain all of the, the entire geometry and pretty much, I would say I am actually different like, the edges of different features, like you know if there was a pyramid in the middle, I would find that point and I would locate it on the top plane of the isometric, I would try and explain to them that this is where that is because of dimensions. And draw from there.

When describing the creation of a pictorial, P15 said, "I would take the different views, the side view and top view, and kind of put it together..." P13 said creating pictorials from multiviews is visualizing with the mind "how each piece fits together and then just connect them."

Relative to the course, none of the participants in the group thought that they had improved their spatial ability. For example, P16 said:

> I agree and say it didn’t necessary improve it. I guess it has made me aware that I have pretty good spatial ability, but I don't, the class helped a lot with how features are drawn from like different views and perspectives like cylinders in an isometric view, like the ellipses you have to draw, like that made me a little more aware of how things will look from a certain perspective.

However, all the participants within group A thought that sketching was the most vital part of 163 in developing spatial ability. Most thought that the sketching exam was not difficult. P14 described the sketch exam as "pretty stress free," while P13 said it made her "feel good" because she actually knew what she was doing.

4.6.2. Focus Group A Structural Description

Focus Group A acknowledged that hands-on toys such as Legos, as well as a pattern of visual thinking characterized their background experiences. Overwhelmingly, they all acknowledged math as their favorite school course. All of the participants were able to describe verbally the creation of multiviews and pictorials. Moreover, all the participants said that they did not believe they improved their spatial ability in the course.

4.6.3. Focus Group B Textual Description

When asked if they thought they had improved their spatial ability, the participants responded negatively. None of them thought the course improved their spatial ability. P23 said:

> I feel basically about the same as I did before just because I, I've taken some other courses like AutoCAD and architectural drawing in high school...I mean, I think there, you can only get so far, so good at it like, you can, you can only see so much in your mind I mean, I can, see a pencil in your mind but like, it’s, it’s hard to develop beyond just a certain extent so I, I don’t know, I feel like I'm just about the same as I was in the beginning. Maybe a little bit improved, but um, not too much.

P21 concurred, "I wouldn't say the course has helpful in helping you visualize stuff, um, I mean, it does help you in CATIA."

Given their experiences in the course, I asked the participants to describe in their own words what it means to visualize something. P21 described visualizing as:

> ...being able to see something for its abstract properties, it gets better than what it is... I guess like, not looking at if you see, say just takes some, something simple like a screw if you see a screw you don't look at it as a screw. You see it as a cylinder and like, the actual shapes are properties of the object.

P19 described visualization as:

> Something which is not in front of you, I guess, or if you visualize an object, something which is away from or blocks something from that. So you can just guess what it is by what is up there. By knowing the different properties of objects from one view and other views.

P23 described it as:

> ...just taking an object and seeing it in your mind and being able to like rotate it around and see, see it from all different angles, like, but just being, just being able to spin it around in your mind and to be able to see a different views without um, maybe being able to see them, see it 3D on a piece of paper.

Although the participants originally stated that they had not improved their visualization, several acknowledged learning techniques and standards related to drawing. For example, P20 stated:

> Before taking this course I would say it [doing the multiview sketches] would be difficult for me but like after taking this course I find sketches pretty simple and I think we were taught a process and I followed that and I would probably follow that if it was, if I had to do it again.

However, the participants acknowledged their difficulty with pictorial drawing. P19 stated it best when he said:

> When you have, like, when you have the actual object in front of you, it’s kind of easy for you to draw the different views. But when the views are given, it’s kind of hard for you to, to guess what's up there, or to, I find it difficult to visualize.

The group acknowledged that a process was taught for pictorial creation, but doing them was still difficult. P20 acknowledged:

> I found it more difficult. But I just I tried to use his method and I think went in for help because I don't know, I found it more difficult to do, so, I tried to use the A-A, B-B method, whatever that method was, but it seemed to work once I like got a hold of it like it took a couple practices. I think I had to use another piece of paper or something.

P19 recommended something that helped him with working on pictorial drawings. He explained:

> This is what my father had advice for me actually, he has taken mechanical so, he's pretty much with drawings and stuff so. So he said like, start with one of the objects and draw the orthographic stuff and then leave it, as such, and say after a long time, take back the orthographic view and then start creating the actual object from that. So you know where you are going wrong and stuff.

None of the participants could describe verbally the process of pictorial creation. Instead, they thought they would have to show it.

Although the participants had difficulty with pictorial creation, they all stated that they enjoyed the course and activities within it. P21 said:

> I love the challenge of trying to figure out a problem, which, at the beginning of the semester I wasn't really like, I find the sketching and the um, orthographic views a lot easier than modeling something in CATIA. Um, but I enjoy it even now, like I've gotten help on the last couple projects from one of my friends whose in the class and but I still enjoy it even though I don’t like the computer work as well as the hand drafting.

P19 agreed:

> At first I had some difficulty in comprehending what Professor was saying, he was kind of fast, the class on the whole was towards the end it was really interesting I guess. Like you could comprehend almost all he was saying. It’s kind of of like that.

4.6.4. Focus Group B Structural Description

Each of the participants within group B did not think that they had improved their spatial ability through the course, even though they stated that they enjoyed the course and most of the activities in it. While the participants were able to describe verbally what visualization meant to them, none of them could describe the process of pictorial creation. Although they found creating multiviews easy, pictorial creation difficult—even when they used the process described in the course.

4.6.5. Summary of Focus Group Findings

It was intriguing to find that neither focus group thought that they had improved their spatial ability through the course. Nevertheless, as suspected, the high ability group was able to describe both pictorial and multiview creation, whereas the low ability group could not. The background experiences of the high ability group agreed with the data from the interview participants.

4.7. Additional Data Sources

While the primary data sources for this study were the participant interviews and focus groups, several other data sources were used to corroborate emergent data. The sources described in the following sections include the final epoché session, course performance data, and MRT posttest results.

4.7.1. Final Epoché Session

Following the transcription of all the data sources, I conducted a final epoché session:

> Now that I have concluded all of the interviews and the transcription of them, my thoughts towards spatial ability have changed somewhat.
>
> First and foremost, I am absolutely amazed at the range of backgrounds and experiences of the interviewees. It is quite staggering the connections a number of the interviewees made between their experiences growing up and their spatial ability. As well, I noticed several things about high visualizers and low visualizers while I was transcribing the data. Also, it appears to me that most people are not truly aware of their own level of spatial ability. Some who are high believe they are only average and some who are low believe they are better than they are. This was quite surprising—particularly the high ability students. It is hard to determine if they are simply modest or that they truly do not understand the level of their spatial ability.
>
> Nevertheless, my perception of spatial ability has changed somewhat due to a combination of statements in the literature and what I saw exhibited in the students both during the class and in the interviews. Prior to the interviews I feel like I probably had a pretty "nurture" based view of spatial ability—that is, that spatial ability is more formed by experiences than anything else. However, some of my subsequent readings in the area have convinced me that there is likely a balanced effect of both nature and nurture on the development of spatial ability. Some researchers go so far as to credit biological factors such as brain development, hormones, or heritable traits as the primary contributing factor. However, my view is that these biological factors combined with environmental ones probably equally affect spatial ability development.

4.7.2. Course Performance Data

An additional data source that seemed relevant to the statements made by the participants was in relation to their course performance. Table 4.7 shows the performance of the high and low visualization interview participants, and the high and low focus group participants. Note that the percentages shown in Table 4.7 are based on a scale of 100 to 89 yields an "A", 88 to 79 yields a "B ", 78 to 69 yields a "C ", 68 to 59 yields a "D ", and 58 and below yields an "F."

Table 4.7.

Participant Course Performance (Based on Total Percentages of 100).

High Visualization Interview Participants				
Participant	Assignments	Sketch Exam	CAD Exam	Final Score
01	93%	76%	76%	89%
02	94%	87%	93%	97%
03	93%	81%	88%	91%
04	93%	63%	92%	87%
05	94%	75%	96%	94%
06	94%	75%	87%	90%
Low Visualization Interview Participants				
Participant	Assignments	Sketch Exam	CAD Exam	Final Score
07	92%	45%	30%	64%
08	81%	38%	78%	72%
09	91%	82%	82%	86%
10	91%	75%	77%	87%
11	87%	48%	57%	70%
12	92%	52%	70%	77%

Table 4.7 (continued).

Participant Course Performance (Based on Total Percentages of 100).

High Visualization Focus Group				
Participant	Assignments	Sketch Exam	CAD Exam	Final Score
13	90%	92%	88%	94%
14	96%	91%	84%	91%
15	92%	93%	74%	92%
16	85%	93%	83%	89%
Low Visualization Focus Group				
Participant	Assignments	Sketch Exam	CAD Exam	Final Score
19	93%	39%	90%	81%
20	82%	91%	51%	80%
21	86%	69%	54%	71%
23	88%	63%	95%	82%

4.7.3. Posttest MRT Results

Table 4.8 shows the pre- and posttest MRT scores for all participants. All participants (except P01 and P20) equaled or improved their scores on the MRT. P01 significantly decreased and P20 did not take the second MRT test.

Table 4.8.

MRT Pretest and Posttest Scores for Participants in the Study.

Participant	MRT 1	MRT 2
High Visualization Interview Participants		
01	19	11[1]
02	19	19
03	19	20

Table 4.8 (continued).

MRT Pretest and Posttest Scores for Participants in the Study.

Participant	MRT 1	MRT 2
High Visualization Interview Participants (Continued)		
04	19	18
05	18	18
06	18	18
Low Visualization Interview Participants		
07	7	10
08	5	13
09	11	18
10	11	16
11	14	16
12	14	14
High Visualization Focus Group Participants		
13	19	20
14	19	18
15	19	18
16	19	20
Low Visualization Focus Group Participants		
19	10	20
20	8	N/A[2]
21	12	13
23	15	17

[1] While most of the high ability students received very similar scores, P01 dropped significantly. While she was not asked about it, I believe this was due to background circumstances going on at the time of the exam and not truly indicative of her ability.

[2] P20 did not take the second MRT exam due to being absent from class the day it was administered.

4.8. Summary

This chapter has presented the data from the various sources gathered and examined in this study. Through the first interview, the background and experiences of the participants was examined. The second interview provided insight into the participant feelings, processes, and approaches to spatial problems. The third and final interview prompted the participants to reflect on what they had learned and how they had progressed over the semester. To complement these, data from focus groups, course performance, and MRT posttest were used.

The next chapter draws upon the data referenced in this chapter, to examine the overall themes that emerged. It will summarize and corroborate the data in regards to the questions posed by this research.

CHAPTER 5. THEMES AND ESSENSES

The prior chapter reviewed the various data sources, presenting the horizontalized data, textural and structural descriptions for each participant, as well as initial source summaries. This chapter integrates the various data sources, reporting the invariant themes that emerged. The chapter introduces each theme as it emerged for high and low spatial ability participants and provides supporting narratives.

5.1. Themes Across All Data Sources

A review of the various data across each of the sources revealed several emergent themes, as shown in Table 5.1. The sections that follow provide explanation of each of these.

5.1.1. Background and Experiences

While the predominance of the background and experience oriented themes came from the first interview, they were often corroborated in subsequent interviews as well. While the first interview focused on a wide variety of experiences—from childhood toys to sleeping habits—many of the areas of questioning did not yield insightful conversation. However, four areas seemed to surface as topics the participants believed were highly relevant to spatial development or experientially important during their maturation. These included childhood toys, favorite school subject, musical experience, and involvement in sports.

Table 5.1.

Five Themes Emerged in This Study.

Themes	Description
1. Background and Experiences	Emergent areas of interest included childhood toys, musical background, favorite courses, and involvement with sports.
2. Characteristics	Notable similarities or differences between ability levels while problem solving
3. Common Errors	Observed or reported errors made in solving spatial tasks
4. Approaches and Processes	Techniques for solving spatial problems
5. Feelings	Various feelings observed or expressed by participants

5.1.1.1. Childhood Toys

As discussed in Chapter 2, one of the overarching discussions in spatial ability research is the nature versus nurture argument, that is, which is the source of spatial ability differences. The nature argument posits childhood experiences, as well as access to toys and other experiences, as the basis for the development of spatial ability (Berry, 1971; Conner, Serbin, & Schackman, 1977; Stumpf & Kieme, 1989). Many have conducted research into toys, toy stereotyping, and the effect of toy access on spatial development (Fisher-Thompson, 1990; Tracy, 1987, 1990; Vandenberg, Kuse, & Vogler, 1985).

The biological position argues that due to heredity, hormones, or even genetics, individuals are predisposed to partake in certain activities or to exhibit certain abilities (Hall & Kimura, 1995; Linn & Peterson, 1986; Mann, Sasanuma, & Masaki, 1990; Sanders, Cohen, & Soares, 1986). However, contemporary thoughts on the subject of spatial ability and development argue that it is likely a mix of environmental and biological factors (Allen, 1974; Brosnan, 1998; Casey, Nuttall, & Pezaris, 1999; Harris, 1978; Vandenberg, Stafford, & Brown, 1968).

When asked about the childhood experiences that they thought affected their spatial ability, participants overwhelmingly reported that play activities with physical toys, particularly Legos, were a factor. All six of the high spatial ability participants (HSPs) referred to Legos, as did three of the low spatial ability participants (LSPs). Two of the other LSPs acknowledged having access to Legos, but that they were not something in which they were overly interested as a child. Three of the four high spatial ability focus group participants (HFGs) also acknowledged play activities with Legos.

That the HSPs and HFGs acknowledged Lego play activities was not surprising. In fact, this agrees with the literature (Brosnan, 1998). It was surprising, however, that three of the LSPs (P09, P10, and P12) acknowledged playing with Legos, even though their MRT scores were initially low (11, 11, 14) and their course performance was modest (86%, 70%, 77%). As I pondered this, I returned to the initial data. I wondered if there was a difference with how, or how much, they played with Legos. While indeed all three LSPs acknowledged play activities with Legos, comparing their statements to those made by HSPs, there seemed to be a qualitative difference in the amount of time, depth of play, or the personal significance of the activity.

All three LSPs mentioned Legos briefly; they did not make more than a passing mention of using them. P09 said:

> I don't know, I played with Legos a lot when I was little cause I had a younger brother and so...mom and dad always pushed me to play with him and get excited into, other things too so, um, played with Legos, played outside a lot. I wasn't really into the whole Barbies and girly stuff when I was little. Played a lot of sports and games outside things like that.

P10 and P12 expressed a little more significance of Legos in their experience. P10 said:

> Well I was always a big fan of Legos, and, and K'Nex, anything you could just build stuff with. I've always enjoyed that kind of stuff, working with my hands just, you know, playing around with stuff like that. That was, yeah, those were my favorite things as kids.

P12 made a similar statement:

> ...I really played with the big blocks shapes...that had the like cylinders and like the rectangles and squares and we would like build stuff downstairs with my dad. And then, ah, we were doing that a lot. I did, I had a bunch of Legos too, and I would build on Legos. I was a pretty big tomboy. So, I played with all the guys toys more.

While P10 and P12 spoke as though Legos had more significance than P09, comparing these statements to ones made by the HSPs left the impression that Legos were a bigger part of the high visualizer childhood activities. For example, P02 said:

> Oh, by far and away I think probably, I think related directly to this, even when you came and talked to the class, my favorite toys when I was growing up were Legos. And, I always was putting things together and always just building, just whatever it would be you know. It just, it was, I was a fanatic.
>
> R: Did you have a lot of them?
>
> P02: I had a ton, I mean, just absolute ton of them. I had, I would just cover a ping pong table. Just complete with constructed things and then I'd have everything, all my pieces to build on the floor then too, and I mean I , I, when I told my mom that I had been chosen for this, I mean that was like her first comments was, "oh my goodness, playing with all those Legos as a child has really helped you out." Um, but I would say that, and, and um, building models too. Just seeing how things fit together and being able to hold the pieces and see and be able to see it in all the dimensions before you add it to other pieces. And, I think then you conceptually get and idea for depth and space.

P02's conversation continued for about five minutes about the significance of Legos when he was a child. In the same vein, P06 exclaimed, "I was really into Legos. I was Legos, video games, and outdoors kid." The other HSPs made similar statements that led me to believe their involvement with Legos was greater than the experiences mentioned by the LSPs.

Nevertheless, while the present data are not enough to draw decisive conclusions, it is evident that those with Lego experience scored higher on the MRT, while those who did not play with Legos scored lower. Indeed, participants acknowledged a whole host of other activities, but Legos emerged as an unmistakable, unifying thread.

5.1.1.2. Favorite School Subject

Literature on spatial ability often presents two generalities relative to study in school. The first generality says that high visualizers often have difficultly with verbal skills, including grammar, punctuation, and spelling (Barton, Cattell, & Silverman, 1974; Fennema & Tartre, 1985; Garner, 1993; West, 1997). Second, the literature often touts the positive correlative relationship between ability in math and spatial ability (Aiken, 1971; Fennema, 1974; Fennema & Sherman, 1977; Piascik, 1998; Shea, Lubinski, & Benbow, 2001).

The verbal skills acknowledged by both the HSPs and the LSPs did not agree with generalizations made about the relationship of spatial ability to verbal skill in the literature. There seemed to be no consistency; in both groups there were participants who reported being strong in verbal skills (specifically grammar, spelling, and punctuation) and those who reported being weak in those areas. Similarly, there seemed to be no tendency for the gender stereotype either.

Yet, an overarching commonality found in the data was focused on math as a subject of interest or ability. All of the HSPs acknowledged that math was their favorite course and all of the HFGs said math was their favorite subject also. Background questionnaires from the HSPs and HFGs corroborate this; when asked if they considered themselves strong in math, the participants selected "yes." Table 5.2 demonstrates brief statements made by these participants during the first interview.

Table 5.2.

Participant Statements about Mathematics

Participant	Statement
P01	... I was always ahead in school, like for my grade level in math. And, I don't know if someone got me interested or it just came easier to me.
P02	I mean, math was certainly a favorite of mine, just because I like...the order of it. It just made sense.
P03	I always kind of liked math a little bit more than the other subjects...I always did better in math, so, it always seemed to be the best option. I could always concentrate on it fairly easily.
P04	I've always really liked science and usually math. Sometimes when it was hard, I didn't like math so much, but I still enjoy math a lot and always liked science.
P05	I love, I really do love math. I understand, I want to understand, and I find the basic concepts extremely fascinating...
P06	Um, I was definitely a math guy, anything [math]...

While the HSPs overwhelmingly said that math was their favorite subject, only two of the LSPs said math was their favorite. Additionally, P07 and P11 said that math was their least favorite. P07 said:

> Math, I didn't like. I don't know. It didn't come very naturally for me and I had to put in a lot more work just to like keep up with it. I mean, I wasn't in, I was in like a, like a faster paced class but I wasn't like the best person in there and I didn't like how hard I had to work to do well in it.

Similarly, P11 reported that while he had liked math in the past, his current classes in calculus were "just not clicking." He said, "I'm not liking it anymore."

Based on the literature, P09 and P12 seemed to be unique in that they were low in spatial ability, but high in math interest or ability. Of her ability, P12 admitted:

> P12: I always loved math and science. They're just, I wouldn't say I love it. It came easier for me...

> R: So on math, you said it came very easily. Describe to me, do you have any ideas why it might have come easily for you?
>
> P12: I don't know, exactly, cause I know, I don't know which parent of mine has very strong in math, so I was just kind of, I can understand the concepts maybe. All of it came easier than some people, or maybe I just work at it a little more and I can understand it. Um, and obviously math gets harder as I'm going, so it gets more difficult and, I slack off, which is probably more of my result of like, if I do bad on a test I like, I, I find it fascinating how these scientists came up with these ideas. And I'm just kind of like, how in the world did they think of this?

Although she did not mention it at the time, earlier in the interview P12 acknowledged that she played computer-learning games a lot as a child, particularly a game called MathHeads. In her case, either strong parental involvement (based on her background questionnaire) or playing computer-learning games could be reasons for her strength and interest in math. Similarly, she acknowledged a potential "biological source" in her narrative above as well.

Like P12, P09 acknowledged a strong interest in mathematics. P09 said, "I always enjoyed math...I was always good at math and I always enjoyed it. I had really good teachers for math in high school, so, um, I think that had a lot to do with it." P09 and P12 both said they considered themselves strong in math on their background questionnaire also.

The data seem to corroborate findings in the literature that demonstrate a positive relationship between math and spatial ability. It is assumed that participants performed well in math if they stated that "they liked math" or that it was "easy for them." In the literature, math ability and spatial ability are typically positively correlated: Aiken (1971) .52, Baldwin (1984) .60, Clements and Battista (1992) .30 to .60. Spatial ability has been reported as a good predictor of mathematical knowledge or ability also (Brown & Wheatley, 1989; Burnett, Lane & Dratt, 1979; Fennema, 1974; Fennema & Sherma, 1977; Fennema & Tartre, 1985; Friedman, 1995; Landau, 1984; Mason, 1986; Moses, 1977; Rhoades, 1980; Robichaux, 2000; Tillotson, 1984).

While results from the HSPs agree with the literature, data relative to P09 and P12 seem contradictory. The data garnered in this study do not provide any basis as to why the two LSPs are strong in math but lacking in spatial ability. It must be noted that, when combined with information about play activities with Legos, P09, P10, and P12 appear to have some strong commonality with the HSPs. It is plausible that they were higher in spatial ability than what was measured by the MRT.

5.1.1.3. Musical Experience

Literature on spatial ability includes several studies that show a relationship between spatial ability and musical ability (Harris, 1978; Hassler, Birbaumer & Feil, 1985; Heitland, 2000a, 2000b; Mason, 1986; McKelvie & Low, 2002; Newman, Rosenback, Burns, Latimer, Matocha & Voght, 1995; Rauscher, Shaw, & Ky, 1993, 1995; Rauscher, Shaw, Levine & Ky, 1984; Robichaux, 2000). The results of the present study revealed that while most of the HSPs have extensive musical backgrounds, three of the LSPs also have similar experience. Table 5.3 shows the musical experience of the participants.

Several of these participants reported the ability to "visualize music," that is, the ability to look at music and hear it in the mind, or the ability to hear a musical piece and play it ("play by ear"). Acknowledging Harris' conclusions (1978), Robichaux (2000) said this was likely a type of spatial skill. Uniquely, two of the LSPs said they had this ability. P10 acknowledged:

> I think I could sight read fairly well. I could, look at it, I could hear it in my head...I couldn't always get it out on the instrument right away, but I could look at it and get it going in my head.

Similarly, P12 said:

> I could hear the notes, but rhythm was hard for me, cause ah, I didn't have a good rhythm background so like I would always um, playing how I thought it would be and sometimes that was hard because this is how I thought it would be, but music says no and my teacher and they would get

> on me a lot about that. Cause I usually like to go faster. When, this is supposed to be a little slow and elegant um, but besides like sight-reading and the notes, I was pretty good at that.

I found it intriguing that musical ability was a definite similarity among the HSPs, and it was consistent with portions of the literature. P10 and P12 stood out as anomalies in this aspect. Further, both P10 and P12 reported the ability to visualize when sight-reading music.

Table 5.3.

Participant Musical Experiences

Participant	Instrument(s)	No. of Yrs.	Self-taught	Still play
P01	Clarinet	2	N	N
P02	Trumpet	4	N	N
	Piano	>10	N	Y
P03	6-string Guitar	4	Y	Y
P04	Clarinet	1 month	N	N
	Piano	2	N	N
P05	Clarinet	6	N	Y
P06	String Bass	8	Y	Y
	Bass Guitar	6	N	Y
	Piano	1.5	Y	Y
P07	Piano	2	N	N
	Drums	2	N	N
P10	Tuba	4	N	N
	Sousaphone	4	N	N
	Baritone	7	N	N
	Trombone	1	N	N
P12	Harp	14	N	Y

5.1.1.4. Sports Visualization

The last notable area that emerged as a background or experiential theme was one that I was unprepared to recognize. It was the most surprising "find" amidst the discussions of background and experiences, likely because it was something with which I was least familiar.

The literature on spatial ability seems to say little about visualization applied to sports performance. While there are studies that have investigated the relationship between sports involvement and spatial ability (Glasmer & Turner, 1995; Lord & Garrison, 1998; Lunneborg, 1982), they make little or no mention of visualization for the improvement of performance in particular sports. Nevertheless, several participants reported experiences with visualization that are as vivid, real, and important as any applied task in other subject matters.

During the course of the first interview, four participants (two HSPs and two LSPs) acknowledged the use of visualization in sports. Additionally, two of the HFGs acknowledged visualization use in sports also. P01, P07, and P14 acknowledged using visualization in swimming. P06 and P12 acknowledged it in track, while P13 acknowledged it in tennis.

The richest descriptions of the experience were acknowledged by P01, P07, and P12, as detailed in Chapter 4. In all three cases, the participants acknowledged:

1) The use of extremely vivid mental imagery
2) Representations that included sight, sound, smell, and feeling
3) They did the visualization exercises almost daily
4) Visualization that positively affected their performance
5) Their body would react to their visualization exercises

The similarities across these three cases were surprising because two of the participants were from the LSP group. Plausible explanations for this could have been that P07 and P12 were incorrectly identified as low in spatial ability or that visualization for sports entails the use of a similar, but different mental ability. While the methodology in this study seemed unable to answer why, the descriptions provided by these participants (particularly P07 and P12 from the LSP group) seemed to indicate that while they may be low in spatial ability as measured by the MRT or by their performance in the course, they certainly have the mental capacity to visualize, quite vividly and quite readily.

5.1.2. Characteristics of Varying Ability Levels

The second area of themes that emerged in this study was related to characteristics that I observed, primarily during the second interview. In reality, it was only during the second interview that I became cognizant of these "characteristics"; during the analysis phase, they emerged across the other data sources. I call these characteristics, but they may be more aptly called tendencies.

As the participants worked on the applied problems in interview 2, I noted that the HSP and LSP groups seemed to operate similarly, both in their methods of solving the problems, in their communication during the interview, and in certain physical behaviors. Table 5.4 lists the behaviors that emerged from the analysis of the data. Subsequent sections will describe the differences that emerged relative to physical characteristics and problem-oriented characteristics.

5.1.2.1. Physical Characteristics

While Chapter 4 did not provide much of the transcribed narrative from the second interview (think aloud narrative from the participants), one of the first things that I recognized during the interviews (which was even more apparent while transcribing the audio recordings), was that the HSPs tended to be more verbal while solving problems. For the most part, each HSP provided fluid narration of what they were doing or thinking at all times; often they commented why they were doing something and whether they did it often. Some even provided personal anecdotes or self-criticisms.

Table 5.4.

Characteristics of Participants Based on Spatial Ability Level

Physical Characteristics	
High Visualizers (HSP)	• More verbal while solving problems o Counted Aloud o Types of Comments • Confidence
Low Visualizers (LSP)	• Little narrative while working • Hesitancy / Lack of Confidence
Problem-Oriented Characteristics	
High Visualizers (HSP)	• Worked across views • Double-checked frequently
Low Visualizers (LSP)	• Unable to decompose problem

As an example, the following is a segment from P06 while he was solving problem 1 in the second interview. It is approximately one-quarter of his narrative (or, his description of completing one-half of one of the three required views):

> Ok. Now I am going to, going to look and kind of draw out the lines you can see easily. So I am not worried about hidden lines. [Counting] eight. So then, that's eight across [Counting] and four up. [Counting] Four. [Counting] Two. [Counting] Eight. Ok. This bottom...this whole line is there...that connects down to this line. Now we have two surfaces back here...and extend [Counting] two out from the top. [Counting] Two out from the top. And go down to this main line. And now we have this surface is another two across and it goes down to this main line. So, that stops on that side. And then there's a hidden line that cuts, like...two over... [Counting] Two. [Counting] Six up. So that hidden line cuts over there. And that's all covered by the main lines so we don't need it. So I am working

> on this first hole. [Counting] Two over and three’s the center. [Counting] Make that ghost box. Draw that in... Ok. The only other thing to worry about in this view is this side, which is, um, the edge is only one over...so...one over and that’s it. Ok. So since we have all those views done, we go to the top and just start counting. [Counting] Three. [Counting] Three across. It goes out [Counting] four. Like that...

The above portion of P06’s narrative demonstrates the depth to which the HSPs explained what they were thinking or doing. However, it also demonstrates one other related characteristic of the HSPs: most of the HSPs either counted aloud or said, "I am counting" while they determined measurements on the problems. While I encouraged them to talk aloud as they worked, I did not highlight that they needed to count aloud. They simply did it on their own. This was something particularly unique to the HSP group.

These two tendencies (amount of narration and counting aloud) were particularly evident in P02, P03, P05, and P06 and appeared to be natural and unforced. P02 even acknowledged that he often "talks to himself" as he works the problems at home. Throughout the problem solving activities, the HSPs had little difficulty talking while working and it actually made it quite easy to understand what they were doing.

My observation notes for P10 acknowledged my recognition of both the amount of conversation and counting as potentially endemic of high visualizers. The second interview with P10 was the third that I had done; the two prior interviews were with P04 and P05, both high visualizers. I assumed it was the sharp contrast between the vocal nature of P04 and P05, as compared to P10, that made me initially recognize this. At the time, I wondered if it was simply a gender difference (P04 and P05 were both females); because generalizations in the literature often tout the females are better in verbal skills (Conner & Serbin, 1985; Fennema & Tartre, 1985; Kimura, 1996; Mann, Sasanuma, Sakuma, & Masaki, 1990). However, latter interviews with male HSPs continually negated this (as the above narrative from P06, a male, also demonstrates).

In comparison to the HSPs narrative, the LSP narratives were generally very short. The following excerpt, from P10's narrative of the entirety of problem 1 (all three views), shows the comparative difference between the depths of narrative. Note that the gaps or spaces in which the participant is not speaking have been removed for brevity:

> ...I'm just looking at the basic geometry of the thing, seeing where I need to start. So I'm sketching the real basic shapes first. All right now that I have the basic solid laid out, I'll start doing negative geometry and hidden lines and all that...I guess overall I thinking this is fairly easy. Just making the construction box for my holes. It seems that no matter what I do I cannot get a round circle. I can look at an object and see what it's supposed to be, I just can't, I have issues getting it on paper sometimes. All right, I got the solid view done. Going to do the front view. Now I am done with the construction box for the top view. Doing the same thing as with the front views, just getting the basic shapes down first...moving along fine, I can't do...it takes me time to look at it. Basic sketch and go in and darken up the lines that I need in the...that are actually going to be scene. All right and the last thing I'm going to do here are the holes. Going to draw the centerlines real quick. I just noticed the rounded corner on the one end. Going to look over it one more time, make sure everything looks, good. I think it does. Now I will start out with the construction lines. I'm going to start out with the basic geometry. Now that I have the solid geometry in there, I'll go ahead and do my cylinders...I think I am done, but I want to look over it one more time to be sure. Everything's there... It looks good to me. I think I am done.

Generally, LSP narratives were shorter than P10; P10 and P12 were the longest and most descriptive in their vocalizations within the LSP group. Even so, it is apparent that the LSP narratives were shorter than the HSP narratives. And, while counting aloud was characteristic of the HSP group, as evidenced in the P10's narrative above, he did not count aloud nor acknowledge counting (although he likely was because his solution was correct).

Although I did not wish to heavily influence the amount of narrative provided by the LSPs as they worked, at times, I did prompt them as to what they were doing or encouraged them to speak more. While the latter was ineffective, participants did respond to questions. However, their replies were brief and to the point. For example, P09 had difficulty with problem 2, but had not spoken what she was thinking or doing. I inquired:

> R: Can you see the object in your mind or pieces of it?
>
> P09: Sort of, but not really. I think it helps now that I have the cube on the paper, I can see it better, but like when I first just looked at the multiview, I was like, ok, I really don't know what that is going to be, we'll see if I can draw it. Like it doesn't look like anything that would be familiar everyday object or something like that. It's a little, that makes it a little more difficult. Like I thought, I was getting somewhere and then I lost it. Hmm.

Due to their extremely conversational problem solving, two other characteristics appeared in the HSP group. First, the HSPs often made comments that could be classified as self-aware, self-critical, or questioning. Sometimes the comments were simply anecdotal. While the LSPs would occasionally make such comments, they were much more prevalent in the HSP narratives (approximately a ratio of 5:1). Table 5.5 shows some examples of these.

While the LSPs were not totally devoid of making comments such as these, the frequency of comments made by the HSPs was much greater. Granted, these comments could be simply due to the difference in the amount of talking by each type of participant, but it could also be evidence of the amount or depth of processing occurring. Nevertheless, the vocalization of various comments was a noticeable tendency within the HSPs.

A final characteristic of the HSP group, which will be discussed in greater detail later in this chapter (in the context of other feelings that emerged across all participants), was the confidence exhibited by the HSPs. It seemed logical that the HSPs would indeed exude confidence. Overall, most approached the problems in that manner. One could argue that it was the HSPs confidence that resulted in their greater verbalization. However, as will be mentioned later, they were not always confident—particularly when posed with problem 3. In fact, the HSPs vocalized a range of feelings, but overall their body language,

Table 5.5.

Comment Types Made by HSPs.

Participant	Comment	Type
P01	...labeling these points with letters cause it's a lot easier for me as Dr. Miller showed us in class.	Self-aware
	Kind of thinking I drew the second circle in the wrong spot on my first drawing.	Self-critical
	I am kind of confused by this diamond thing on either side but, not quite sure how to draw it.	Questioning
P02	I've got my wonderful, you know, the negative geometry, the holes. I hate drawing the holes cause I can never draw a circle properly.	Self-critical
	Ah, I forget what these faces are called, too. They are not going to be, um, in the same plane with any of my views. Oblique, that's it.	Questioning
	Usually this is where, [there] would be a TV on, some sports center. I am serious. I am not trying to be a smart ass or anything.	Anecdotal
P03	I am trying to think of this circle back here. Probably have to mark...can't remember what I have to do about that on the back side.	Questioning
	Like that, that's a crappy line. Well, assuming my lines would be, you know, straight.	Self-critical
	I just like to check my work often.	Self-aware
	Hmm, then I check over, usually. Cause I often forget many things. But that's just me.	Self-critical
	Most of my flaws are limitations to my drawing skill. I don't have good drawing.	Self-aware
P05	I don't do one complete feature at the same time, I don't really know why.	Self-aware
	So I am going to just put a line back. So it's still kind of inclined. Um, nope. That's bad. [Counting] I drew my construction box wrong.	Self-critical
	I have this feature that I am still working on. Um, it's just this inclined surface that goes all the way across. Oh, no it's not...What is here?	Questioning
P06	It should be a flat plane. Why are they showing it at a different point? Oh, because that's an angle there.	Questioning
	And I am missing something...oh this inner crease. So, that would be nice.	Self-critical
	So, what the crap is going on here? Oh. So I usually just start by looking over the whole thing to get an idea of what is going on.	Self-aware

communication, and tone presented a steady confidence during the entire problem solving process.

LSP confidence appeared to be lacking. Table 5.6 provides example statements made by the LSPs.

Table 5.6.

Statements by LSPs Indicating a Lack of Confidence

Participant	Context	Statement
P07	Upon starting problem 1	Ok. I guess I am going to start with the front face. And count it...
	Upon noticing a mistake	Ok so, I have that in. I have to move all this down four more, so everything I had. And that means I have to move that too, Oh, man...Ok, and now I just realized that I am only supposed to do that two down. It’s too early.
	Upon noticing a mistake	I forgot to make this rounded.
	Upon noticing a mistake	I did something wrong with this so it’s not like, so like that isn't touching that. I don't know how I did...
	Upon noticing a mistake	I am going to draw that line in. I just realized that it was halfway there so.
	Upon noticing a mistake	I don't know what I am doing wrong. I don't really get how that can be open and then...like how is that the top view of that?
P08	Upon not being able to do problem 2	I know something is wrong. Something is wrong.
P09	Concerning the talk aloud procedure	It’s hard to talk about it and do it at the same time. I don't...it’s a little more difficult.
	Upon starting the right side view in problem 1	All right. Now I have to tackle the side view.
	Upon completing problem 1	And, I think I am done with it. Maybe. Yeah, that's all I got.
	Upon starting problem 2	Hmm. This one is little harder to visualize for me, but...insane.

Table 5.6 (continued).

Statements by LSPs Indicating a Lack of Confidence

Participant	Context	Statement
P09 (Continued)	Upon trying to draw the isometric box in problem 2	Mmm, see if this fits.
	Upon not being able to do problem 2	I thought I was getting somewhere and then I lost it...This is really hard for me.
	Upon starting alternative B	Hmm. [Sigh]
P10	About doing applied problems in interview 2	Oh good, more CGT work. [Laughs] Pretty much it.
	About doing applied problems in interview 2	I, I, the thing I'm worried about not necessarily worried, I just know I take me time with things and, ah, I'm just thinking this person watching, hurry up and get it done!
	Upon starting problem 1	Oh, gosh. Now what'd you say you wanted here, a multiview?
	Upon noticing a mistake	....Not a big deal with counting issue
	Upon finishing problem 1	It looks good to me. I think I am done.
	When working on problem 2	I'm having a hard time with this drawing. I'm just thinking now that I am a dumbass here.
	Working on problem 2	Had to look at that incline to make sure I didn't screw it up.
	Finishing problem 2	Ok I think I'm done.
	Starting problem 3	Hm, Hm, Hm. Well it's definitely a complex one. First thought this might be a little above my skill level.
P11	Working on problem 1	This piece, here in the back, kind of tricky.
	Finishing problem 1	I think that's it for problem 1.
	Starting problem 2	I guess it would be easiest to start in the top left, here in the front, I mean side view.
P12	Upon starting problem 2	Oh, crap. Ok. Um, first, I would kind of see how it all fits together, I kind of fold the top and side view kind of like a box in my head.

The prior statements provide a glimpse into the hesitancy and lack of confidence exhibited by the LSPs. Often their body language, facial expressions, and tone of voice would enhance statements such as, "And I think I am done with it. Maybe" or "I guess I will [do something]..." For them the spatial experience was full of uncertainty, whereas the HSPs, even when catching a mistake or tackling a complex problem, spoke and acted with relative confidence.

5.1.2.2. Problem-Oriented Characteristics

Aside from the evident physical characteristics, the participants also displayed characteristics relative to the problems they were doing. First, I noticed that the HSPs had the tendency to work across views more frequently. When doing problem 1, this manifested itself in them using the views they had already drawn to complete views on which they were working. In problems 2 and 3, it manifested in them referring to the problem stimulus (and at times drawing directly on it) to compare the provided multiviews.

I actually noticed the amount of looking across views in interview 2 with P04 (the first of the second interviews) as described in my observation notes, "She is studying the drawing intently; doing a lot of looking across views." Analyzed data from interview 2 also acknowledged the frequency of this behavior. And, several participants mentioned doing this frequently in interview 3 also. Table 5.7 shows the data sources in which looking or working across views was evidenced as a characteristic. LSPs are not shown because it only appeared in the third interview with P12 when I asked her directly about this.

P13, P14, P15, and P16 (focus group A) acknowledged that they also worked across views a lot. Table 5.8 provides various comments from HSPs about looking across views as they were working.

Table 5.7.

Data Sources That Acknowledge Looking Across Views.

Participant	Interview 2	Observation Notes	Interview 3
P01	Y	Y	Y
P02	Y	N	Y
P03	Y	Y	Y
P04	N/A[1]	Y	N
P05	N	Y	Y
P06	Y	N	Y

[1]Interview 2 data was lost due to recording error

In comparison, the LSPs did not appear to be working across views. For example, my observation notes for P10 working on problem 1 acknowledged, "Does not appear to be looking across views very much. Is predominantly looking at the pictorial rather than checking front view on orthographic views. I noticed that earlier interviews students looked back and forth across views a lot." I noted the same thing later in problem 2 when I said, "Participant is not looking at the orthographic views much. Is working on the double angle but not looking at orthographic views." Throughout the LSPs interviews, I noticed repeatedly that they seldom appeared to be working across views.

The second HSP characteristic that emerged was the frequency with which they double-checked themselves. This manifested itself in two different ways. The first was when a participant would get a major portion of a drawing done (e.g., a view in multiview or a feature in a pictorial). He or she would stop and check what had been completed. When drawing multiviews, the HSPs would often compare their solution view to the problem drawing as well as compare their solution views to one another. When drawing a pictorial, the HSPs would compare the isometric version of the feature with the multiviews in the problem stimulus.

Table 5.8.

HSP Comments about Looking or Working Across Views.

Participant	About "looking across views..."
P01	I usually constantly look across the views.
P02	I just never really thought about things like that. When you're doing the sketch, you never dwell on if you're going from one to the other. I mean, you have to reference back and forth obviously... I guess you have to sort of look at all three in my mind. You have to be continuously relating to all three of them so you know what it looks like. I mean, there are three views. It's a three-dimensional object. If you just work off one...I think you might have some discrepancies and it might not look correct.
P03	Like if you get, if you can't do one view completely, you got two more views to go on. Half of the time, I can figure it out in some other view.
	Yeah, like if I'm ever confused, like they all line up, like perfectly, like even if you need to, like you could line up your top view and your right view. I mean, it's an extra sketch that's not needed, but if you do it in lightly, if you are actually having that much trouble.
P04	So I can see from these two views that there is a flat, single box with line coming right about here.
P05	...you can only get so much from one view, that's why it's a multiview. So. you have to keep looking over at others to try to figure out piece by piece, "Ok this piece is going, based on this, this piece comes out based on this, this piece, you know looks like this," ...I mean I have, I can't focus on all of them at the same time. But you have to utilize the other two to understand one.
P06	Pick your base view and then from there build on the other parts of it. Because if you're trying to use 2 or 3 different views, as you know, as kind of the base view, you'll screw it up really easy. But if you kind of use one view as like your, this is set in stone, I'm going to think about everything from this one view, and then you build onto that view, and you build from this, you know, 2D and then into a 3D view, then it's a little it easier to construct it in your head, than it is to, just to try to take all three and throw them together.

The second way this manifested was in real-time, as they were drawing. The problems the participants completed required that they count blocks for measurement. HSPs would count blocks in the problem drawing, draw it out in their solution, and then recount the problem drawing again, and count in their drawing to check it. P02 described it best when he said:

> I always like to double, double-check. My dad always said when you were like working with lumber or anything, you always measure twice, cut once. It’s kind of the same. I kind of try to use that same principle when I am doing this as well.

Many of the HSPs acknowledged double-checking their work, often doing both types of checking several times for each problem. Again, while the LSPs were not void of checking themselves, they typically only checked themselves at the very end of the problem. It was not evident that they were consistently double-checking (in real time) throughout the problem like the HSPs were.

Aside from their lack of working across views and infrequent double-checking, a common thread amongst the LSPs was their inability to decompose the pictorial drawing problems. Generally, all of the participants were able to do the multiviews in problem 1 (see Chapter 4). While they frequently forgot lines or features in one or more views, they all were able to solve the overall basis of the problem. However, concerning the pictorial construction, the LSPs seemed to be unable to break the problem down, or decompose it, into simpler geometry in order to solve it. However, most of them, when given the alternatives (which were decomposed from problem 2), were able to solve the alternatives.

Recall from Chapter 4 that problem 2 was designed to be a composite of simpler geometric pieces. As acknowledged in Chapter 4, the alternatives given to the LSP were parts from problem 2. Table 5.9 shows the LSPs that were able to solve problem 2 or its component parts.

As shown in Table 5.9, P10 was the only LSP to solve problem 2 (and problem 3). Three other LSPs were able to solve one of the alternatives, and two of the LSPs could not solve any of them.

Table 5.9.

LSPs Who Solved Problem 2 or Its Alternatives.

	Did they solve...		
Participant	Problem 2	Alternative A	Alterative B
07	N	---	Y
08	N	---	N
09	N	---	Y
10	Y	---	---
11	N	N	N
12	N	Y	---

When an LSP could not solve problem 2 (and before giving them an alternative problem), I asked if they could visualize the problem. For example, I asked P09 if she could see the object in her mind or pieces of it, she said she could not. I also asked P12 the same question. She said:

> I can tell that...I am going to have two holes going through the top prong-looking things. And then this surface is back compared to this front surface. Hmmm, that line is hidden.

This led me to believe that P12 could indeed see at least the top part of the object, but from there she did not know what to do. Thus, I gave her alternative A and she was able to draw it correctly.

Given that three of the participants were able to solve portions of problem 2 (the alternatives), but not problem 2 itself, I deduced that the LSPs did not seem to be able to break a problem down. Instead, they were either trying to visualize the entire object and could not, or would visualize a part of the object but not know what to do next. Several of the HSPs acknowledged that being able to break the problem down (spatially) for mental comparisons (such as the MRT) or visualization (on the sketching problems) was critical. However, once broken down, the LSPs then needed a procedure to help them draw it; they could draw pieces but several said they did not know how to connect them or draw them as a composite object.

This acknowledgement by the HSPs and the difficulties of the LSPs lead to the discovery of a process to assist both high and low visualizers in creating pictorial drawings from multiviews. Of the findings of this study, this process seemed most important because it could potentially influence how students are taught to create pictorials from multiviews. This will be discussed in more detail in section 5.1.4. Before addressing it, I would like to acknowledge two of the most common errors that emerged during the problem solving session in interview 2.

5.1.3. Common Errors

The first of the common errors was mentioned at the end of the prior section. It was the inability to decompose spatial problems and it was particular to LSPs. Said another way, LSPs could not figure out where on the object to start (visualizing or drawing) because they could not simplify the object into its component 3D geometries. When given the simplified object, they could then create the pictorial of the simplified object. This conclusion led to a related, but important question as well.

Although all the participants were able (for the most part) to solve the multiview problems, the inability of the LSPs to decompose 3D objects gave rise to the question: how successful were they at decomposing 2D geometries? In reviewing the solutions to problem 1, except for P01 (who, as noted in the last chapter, seemed to rush through interview 2), all the HSPs either got the entire problem correct or forgot one line (coincidentally, the same line). Whereas, all of the LSPs either misaligned the holes (assumed to be a counting error) or forgot a variety of hidden lines associated with hidden features or the oblique surface.

Is it plausible that errors in deconstructing the 2D geometries were the reason for the LSPs missing the hidden lines (or misaligning the holes also)? Or was it that they simply rushed through the problem and did not adequately check themselves? Was there a common decomposition error among the HSPs that caused several of them to forget the exact same line in the exact same view or was it simply coincidence?

The present data cannot answer these questions. To investigate this aspect, future studies should be executed with (1) a series of multiview problems only (of increasing complexity), (2) observation notes that detail the exact order of lines and features drawn by the participants, and (3) questions specifically probing the participant about multiview drawing.

The second common error was indicative of all participants and was related to the creation of pictorial drawings. All participants had difficulty centering the pictorials on the solution grid paper. Many of them acknowledged that they did not know how to do it. Most just guessed, and many that guessed had to erase and start over, finding that the object would not fit on the paper. Others, who got too near completion to erase and start over, just let the object run off the page.

As mentioned in Chapter 4, after the first interview in which an LSP could not solve problem 2, I added the alternatives. I also decided to use the remaining extra time to provide instruction on how to create pictorial drawings. While most of the HSPs did not need instruction on creating pictorials (most finished both problem 2 and 3), I did give each of them instruction on how to start the pictorial drawing (via an isometric box, which most of them were using anyway) so that it would correctly fit on the page.

In addition to presenting the process for creating pictorials, the next section also provides a very simple technique (that I was aware prior to the study) for centering pictorials on the page.

5.1.4. Approaches and Processes

As the prior section acknowledged, one of the major findings of this study was the emergence of a process that can be used to generate pictorials from multiview drawings. The process became evident from watching HSPs and LSPs solve problems, but it was also due to watching the course instructor and re-experiencing the spatial ability phenomenon for myself (e.g., examining how I solved the problems).

Prior to outlining this process, there are three other notable themes relative to problem solving and approach worthy of note. These themes highlight how the process became evident and why it seemed to provide what the LSPs needed to be able to solve the pictorial problems. The following sections address these points and then describe the pictorial creation process.

5.1.4.1. Solving MRT Tasks

Information-processing research has focused intently on problem solving strategies in spatial tasks (Carpenter & Just, 1986; Cooper, 1980; Cooper & Mumaw, 1985; Lohman, 1984; Mumaw & Pellegrino, 1984; Pellegrino, Alderton & Shute, 1984; Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990). Although few (if any) have used a qualitative approach, this body of research indicates that there are differences between problem solving approaches in individuals (both the content and procedures of the steps and their order). This often leads to differences in problem solving efficiency and effectiveness. As well, the research indicates that individuals strong in spatial ability may have multiple strategies and that they may fluidly change strategies while solving problems.

Given this background, I was curious of the approaches used by the participants for the problems in interview 2, as well as the MRT. Through the interviews, several of the participants acknowledged how they solved the MRT test items. Many of the participants, particularly the HSPs, acknowledged using a part analysis approach to the MRT. While they compared the stimulus object to the discrimination objects, they were looking for particular features in their object comparisons. In their mind, they had decomposed the object, looking for unique characteristics. For example, P02 said:

> I mean, I could look at it and I could almost instantly tell you, "all right that's definitely not it and that ones not it"...just how when you would see like the blocks going one way and another way. I don't know, just like the feature of itself, like I could look at the next picture over and see that the bend was like opposite. It was like, you know, instead of going to the right it was going to the left or something like that. That was primarily what I started looking for. I was really just starting to pick one end, I mean on there, when some of them would get kind of complex.

In this segment, P02 acknowledged reducing the block configuration to a specific feature for comparison. P03 said it another way:

> P03: Sometimes I would like try to rotated it with my hands, sometimes I would just draw a line in, I mean, my steps, really I didn't do more than a which one matches or doesn't match and cancel that out. Usually I could always find one simple point, I don't know if you want me to describe this...
>
> R: A point on the object? You looked for pieces of the object?
>
> P03: Yeah, small things like that...

Statements such as these by the HSPs led me to believe that they had an ability to break spatial problems down. In the case of the MRT, they were able to find identifying features of the objects and use those to discriminate quickly which objects were the same object. LSPs did not indicate how they were solving the MRT, only that many of them found it difficult. This was the first indication that HSPs had a method for breaking down spatial problems that LSPs did not.

5.1.4.2. <u>Approaching Pictorial Drawing</u>

Data from interview 2 and 3 further solidified my assumption that HSPs had the ability to decompose spatial problems for problem solving. Throughout the interviews, several of the HSPs highlighted the importance of breaking a problem down, as did the course instructor. For example, when working on problem 2, the CI said he would work on a "feature at a time" on the object. P01 said:

> Um, I think I would like, take piece by piece...and then how all the ellipses and other pieces, try and connect by looking at the other views...I had to focus in on little pieces, and it didn't like all come together, start like coming together until I had most of it done.

P01's statements, using words like "piece by piece," "connect," "little pieces," and "all come together," indicated that she was decomposing the objects mentally. Similarly, P03 admitted:

> ...what I do is I just kind of look at that [multiviews] and I can sort of, like, if I can't visualize the whole thing, sort of a process is like I could probably visualize that like at an angle, cause like...I can see something like that in my head. And I can like start connecting the top view, start connecting the right side view, see what it's like in the front to view and all that.

P03 said he could not visualize the whole object, thus he decomposed it. Like P02, he used the word "connecting" in his description. P05 described:

> Typically, cause this one [problem 2], I am having a little bit of a problem visualizing altogether. I can see pieces, like from this side one, I can see that this corresponds to this, um, and the holes, but, what I am going to start by doing is sketching the very front and sketching everything that is on the very front of the object, which is just going to be this [she will draw one piece of the object].

P06 provided probably the best description of problem decomposition. He recommended:

> I would say always try to break it up. I think the main problem, if you're trying to go from multiviews to 3D views is you're trying to look at the entire piece all at once. And so, I know I do that and you kind of like, I screw stuff up because when you're looking at everything, it kind of, it's easy to get real messed up. But if you break it apart into easier sections, and easier blocks, and you know, break it up three, four, [or] five different parts then you can, it's easier to visualize each of the parts and then it's easier to put them altogether and it's easier to just kind of think of the entire thing in one piece.

As I reviewed their think aloud protocols, it was evident that the HSPs had broken down the problems as P06 described. My observation notes attested to my belief that they were decomposing the problems. For example, for:

- P01 I wrote, "Decomposing features?"
- P03 I wrote, "Using CSG [constructive solid geometry] approach to construct the top U-shape."
- P04 I wrote, "Decomposing object into processible [*sic*] chunks"; "Approaching it feature by feature."

By examining HSP processes and approaches to the MRT test, the pictorial problems in interview 2, as well as my observation notes, it was evident that HSPs were using mental decomposition or deconstruction techniques in their problem solving, whereas LSPs were not. And, because LSPs were able to solve some of the pictorial problems (when given the alternatives), it became evident that they needed instruction on deconstructing problems mentally.

Yet, as acknowledged in the next section, there seemed to be two parts to pictorial problem solving: visualizing and drawing. Concerning visualization, it appeared that LSPs could not deconstruct problems. Nevertheless, I also discovered that they had problems drawing; they had no procedure for reconnecting deconstructed pieces on paper. The next section describes how I became aware that there are separate processes for visualization and drawing.

5.1.4.3. Sketching Versus Visualizing

One of the common statements made by many of the participants was that they could see a problem object in their mind, but were concerned with getting it on the paper. The first participant to acknowledge this was actually the course instructor. While working on problem 2, he said that he could see the compound angle on the object (he could visualize it) but getting it on the paper was the problem. This statement was vocalized repeatedly by several participants. Table 5.10 shows some representative examples of such statements.

Table 5.10.

Example Statements Showing the Contrast between Visualizing and Drawing

Participant	Statement
P02	I mean in my mind I see it, now it's just a question of can I transfer it to a sheet of paper and make it look reasonable.
P03	Starting to look a little easier. I can see that this is just the left side here, I can see right here that this plane, or this piece right here and right here, and this little box right here is dealing with this. This up here is this. I guess ht hardest part is finding a starting point. All right this is going to be hard to draw.
P10	I can look at an object and see what it's supposed to be, I just can't, I have issues getting it on paper sometimes.

While the prior statements directly address this issue of being able to visualize versus draw an object, several other participants addressed this issue in ways that were more indirect. These statements seemed to indicate that having a drawing process to create on the paper what was in the mind was as important as the mental visualization of a problem solution. This led to the development of two processes for the creation of pictorials. One process, which was really more of a set of questions, dealt with visualizing the object or parts of it. The second process was a systematic method for drawing pictorial drawings. Both are described in the next section.

5.1.4.4. Pictorial Problem Solving

The following two sections describe the pictorial drawing process that evolved during this study. In describing this process, problem 2 (from interview 2) will be used as an example. When LSPs were unable to solve the second problem I used problem 2 for the instruction that I provided at the end of the interview. Figure 5.1 shows the original problem and Figure 5.2 shows its solution.

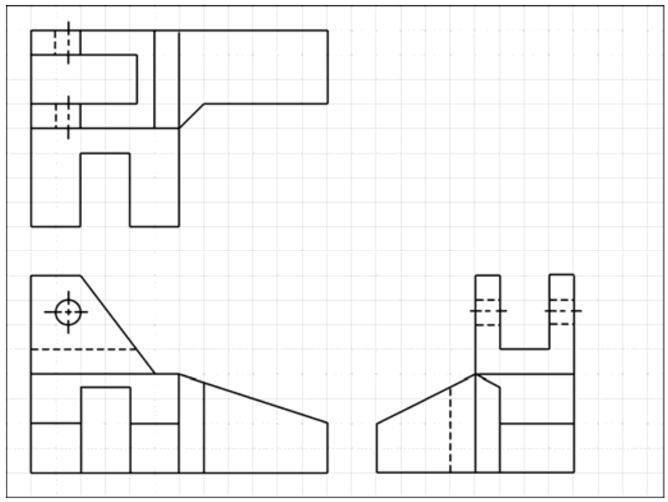

Figure 5.1. Problem 2 from the study will be used to explain the pictorial drawing process.

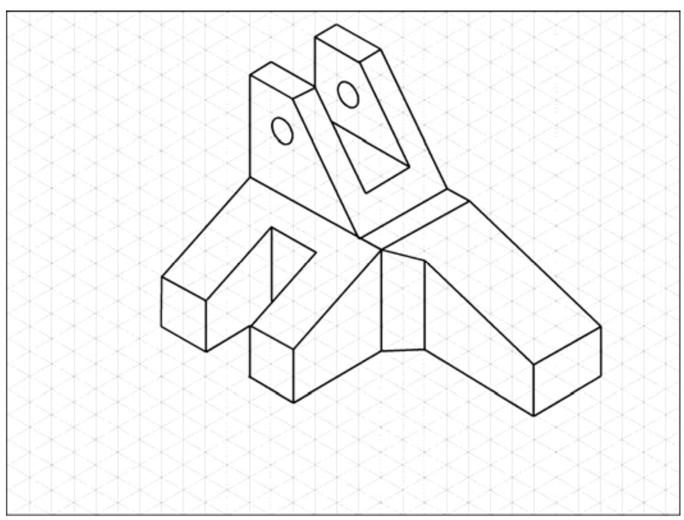

Figure 5.2. The correct solution drawing for problem 2.

5.1.4.4.1. Strategies for Visualization

LSPs could not visualize multiviews, such as the ones presented in Figure 5.1. Persons skilled in visualization can often picture in the mind Figure 5.2, based upon Figure 5.1. In fact, it is highly desirable that students learning to visualize be able to imagine fully Figure 5.2 from Figure 5.1. However, with the wide range of ability levels (and indeed when learning to visualize), it is more likely that students will not be able to visualize the entire object (as evidenced by the LSPs from this study). Thus, I became aware that they needed a method for breaking down the object and visualizing pieces of it. This was the first part of being able to create the pictorial drawing (the second was drawing it).

As observed in this study, too often learners got frustrated with the fact that they could not visualize the entire object—they got frustrated to the point of shutting down or giving up on the problem (P12 was an extreme example of this). However, even the HSPs (and the course instructor himself) acknowledged breaking the problem down into pieces. The LSPs either did not know that it was all right to do this, or they simply could not figure out how to do it.

Therefore, during my instructional time with the LSPs, I provided them some recommended questions they could ask themselves when working on pictorial problems. The first question was whether they could visualize the entirely of the object. I told them that if they could not visualize the whole object that was ok and not to get frustrated. Instead, I encouraged them to decompose the object mentally. I showed them comparative images of problem 2 and the alternatives and said if they could visualize individual pieces it would help them. Figure 5.3 shows an example of problem 2 that visually describes this concept.

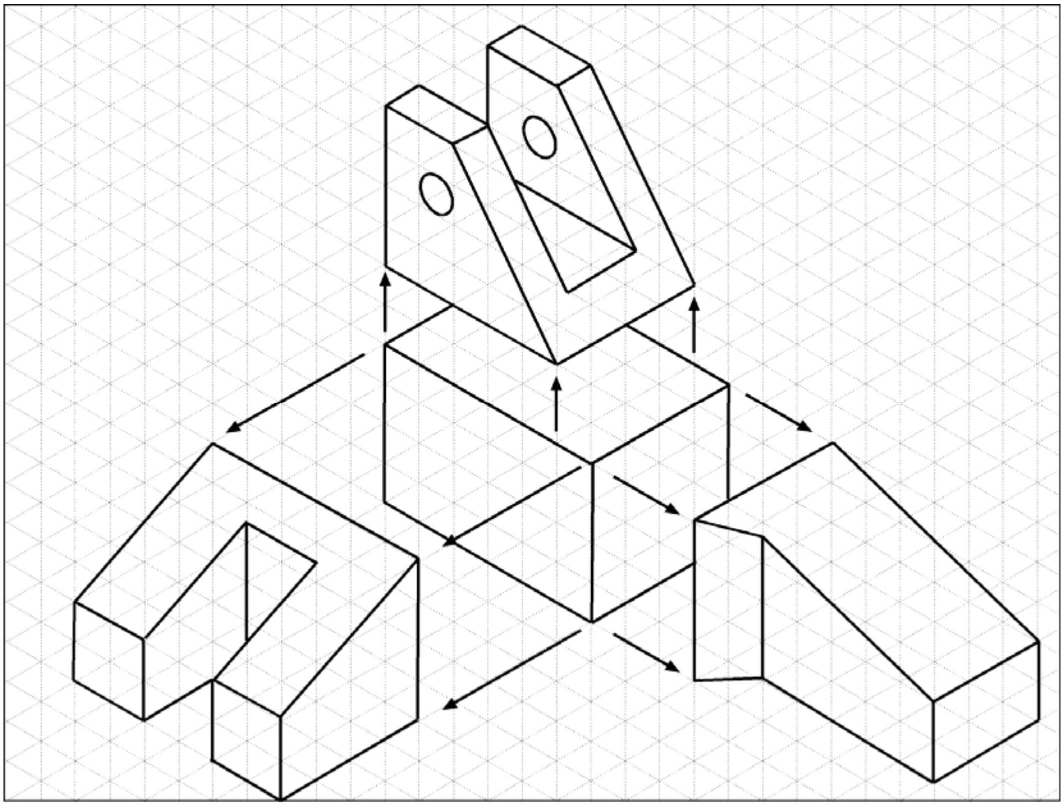

Figure 5.3. Problem 2 decomposed into its component parts.

Most of the LSPs seemed to understand the concept of decomposition and, based on their comments, had never thought of it that way. Once decomposed in this way the object could be started by drawing any of the three primary pieces shown in Figure 5.3.

However, decomposition was not the LSPs only problem. Even if they could decompose the object, they seemed unsure how to draw the multiple pieces in relation to one another (P09 and P12 made specific comments like these). Therefore, I also went on to describe to them that whether they could decompose an object or not, they could create a pictorial, using the process described in the next section.

5.1.4.4.2. Pictorial Drawing Process

While subsequent discussion in this section will provide imagery that shows these steps, the pictorial drawing process can be summarized by the following systematic steps:

1. Draw and center an isometric box on the page that will contain the object.
2. Reduce all features to prismatic features (for example, cylinders become prisms) for construction purposes.
3. Draw visible planes that are coplanar with the front, top, and right sides of the isometric box.
4. Draw visible lines that are coplanar with the right, rear, and bottom of the isometric box.
5. Draw remaining visible planar normals (planes with edges that are parallel to the isometric box planes).
6. Draw remaining visible inclines.
7. Draw remaining visible oblique planes.
8. Draw visible curves or cylindrical elements.
9. Draw remaining negative geometry (holes, slots, and so on).
10. Check and review the pictorial drawing.

The first step in the process is to create the pictorial box and center it on the page. Nearly all of the participants in the study used an isometric box, as shown in Figure 5.4, to start their drawing. Figure 5.4 shows the construction box as a dashed line for clarity.

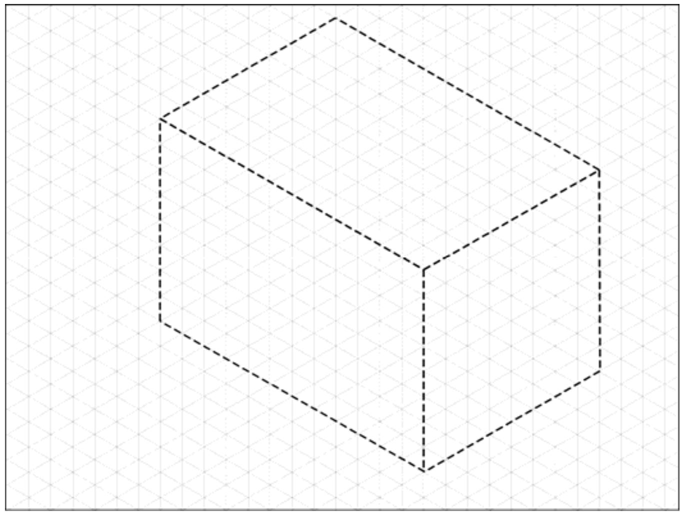

Figure 5.4. Creation of the construction box for the isometric pictorial.

While all of the participants started problem 2 with an isometric box, they could not center it on the page. Therefore, I provided them with the following rules that help with centering the box on the page:

- If the front view is wider than the right side view, start the front edge of the box to the right of center (the greater the size difference the farther to the right the front edge will be).
- If the front view is smaller than the right side view, start the front edge of the box to the left of center (the greater the size difference, the farther to the left the front edge will be).

All participants (HSPs and LSPs) reported that these rules were quite helpful in centering the object.

Step 2 of the pictorial creation process stated that all features were reduced to prisms. This was predominantly aimed at large cylindrical or conical features. While problem 2 had none of these, problem 3 was an example that did (the large loop feature).

Step 3 of the process required that participants draw all of the planes of the object that were coplanar with the isometric box faces. When working with the LSPs, I quizzed them on which faces were and were not coplanar with the isometric box. Figure 5.5 shows an example of the faces from problem 2 that would have been drawn.

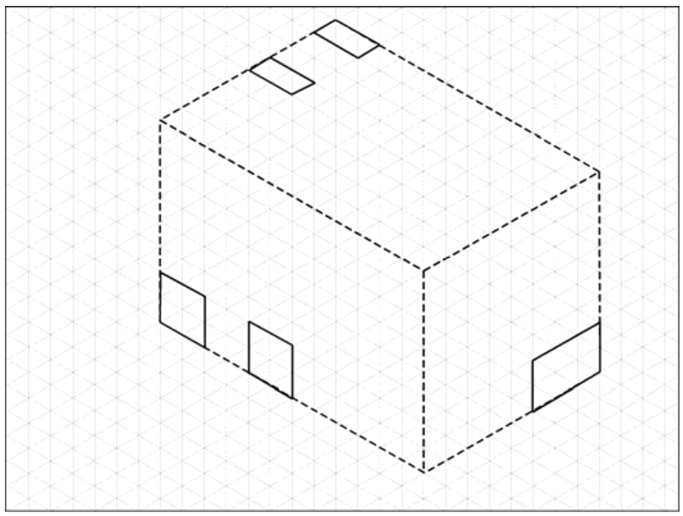

Figure 5.5. In step 3, the faces that are coplanar with the isometric box planes are drawn.

The next step was to draw the lines that were coplanar with the left, back and bottom planes of the isometric box. While this was a little more difficult for the LSPs, I again quizzed them on which lines were both visible and coplanar with the isometric box faces. Figure 5.6 shows the lines from problem 2 that qualified.

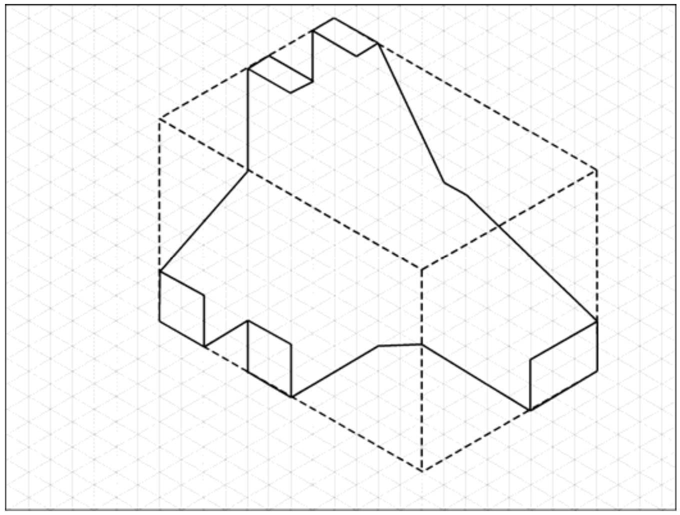

Figure 5.6. In step 4, the lines that are coplanar with the left, back, and bottom of the isometric box are drawn.

Step 5 required that any remaining planar normals be drawn. Planar normals are those planes that are parallel to the isometric box planes, but do not lie in the isometric box planes. Figure 5.7 shows the one plane that was added to the drawing.

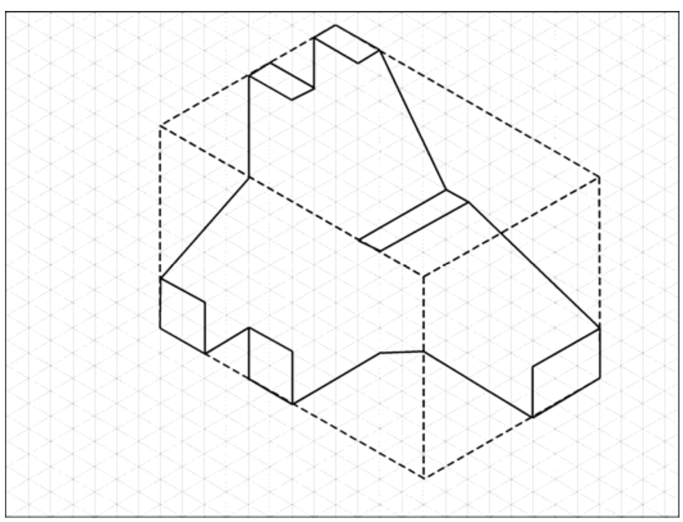

Figure 5.7. Adding the planar normals was the next step.

In Step 6, inclined surfaces are added to the drawing. Problem 2 had several inclined (angled) surfaces. While drawing the inclined surfaces, I provided instruction on finding the termination points on the slots. Figure 5.8 shows the solution for problem 2 with the inclined surfaces added.

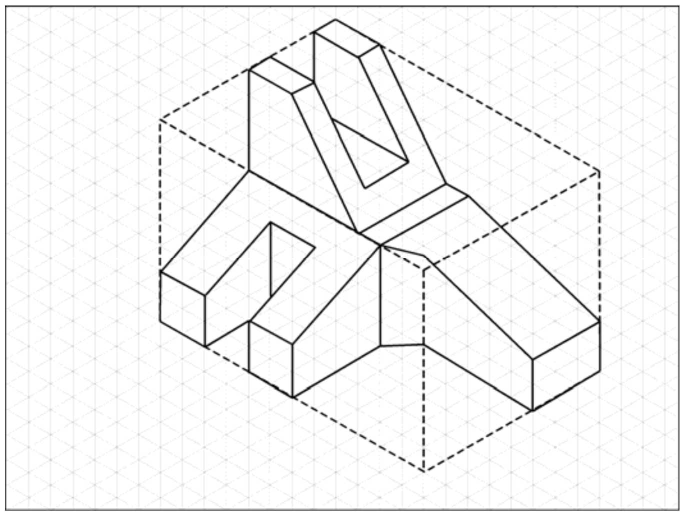

Figure 5.8. Inclined surfaces are added to the drawing.

Oblique planes are typically one of the most difficult things to draw in isometric. An oblique plane is a plane that is not parallel to any of the typical planar faces (front, top, right side). In step 7, oblique planes were added to the drawing, as shown in Figure 5.9.

While problem 2 had no cylindrical or conical features, step 8 would add these types of features to the drawing. Step 9, on the other hand, added negative geometry, as shown in Figure 5.10 (two holes).

The last step in the process was for the participant to review for accuracy. I encouraged all the participants, but particularly the LSPs, to stop and check their drawing when completed. As noted in the prior data, many of the participants did not review their drawings for accuracy. I highlighted the importance of looking across views and comparing planar faces from the multiviews to the pictorial and vice versa.

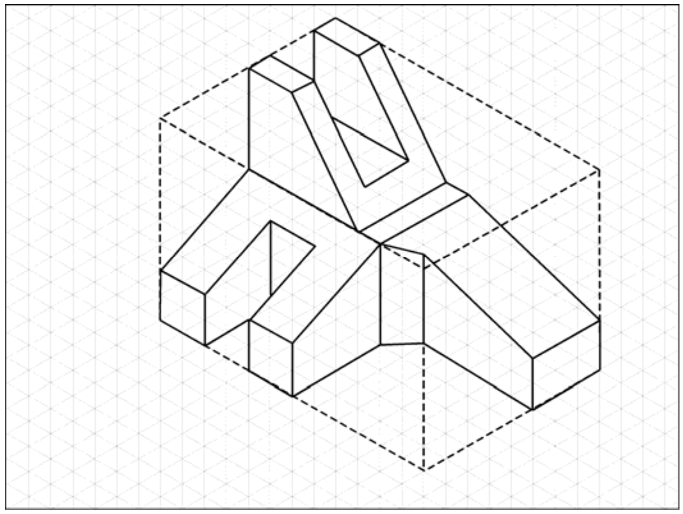

Figure 5.9. Oblique planes are added to the drawing in step 7.

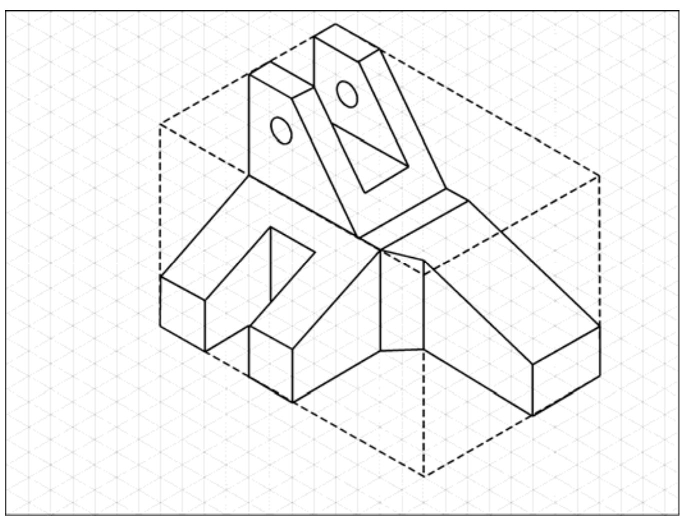

Figure 5.10. Step 9 adds remaining negative geometry, such as holes.

5.1.4.4.3. Student Evaluation of the Process

In the third interview, several of the LSPs acknowledged how helpful and beneficial the pictorial creation process was (specifically, P07, P09, and P12). The pictorial process had impact because the students did not have a defined process for pictorial creation like the one they had for multiview creation. P12 said a pictorial creation process had not been taught in the course:

> ...as I said, that [pictorial drawing] is pretty hard to verbalize, because I don't think I could verbalize that to someone, and I don't know how they [instructors in CGT 163] could necessarily verbalize it to us. But, you know, with going from a 3D view or going from a pictorial to multiviews, you can see that a little easier cause you can like see the shape, like right in front of you, and kind of like, going from the views up, sometimes it’s just very hard for anyone to just like get it right away. And I don't even know if there is a method. Like for them to teach us but like, their not doing it now if there is one.

However, later in the interview, P12 said that the pictorial drawing process helped her:

> ...when you taught me the method for the pictorial views, or going from multiview to the pictorial, I kind of thought, "Oh! That's how you do it." Kind of, or it’s like, how you can start from like pieces and put them together. I thought that was, I mean, very helpful because I don't think like if I had done that, or if you had taught me that I would, I would still be struggling with them today. So I think it’s improving [her spatial ability], because it’s still difficult for me but it’s just like, something like, "Ok, now I can take it apart or put it apart, put it together this way."

Like P12, P07 said:

> Um, that whole thing when you explained to me about the planes actually touch right when you, that helped me so much because before, I don't know, when I pictured it I couldn't picture, like decipher between the ones that were like flat up against it and the ones that were pushed back and it kind of got jumbled in my head. And I don't know that just made it a lot clearer.

Due to the limitations of this study, I was unable to do much more than recognize the pictorial process as it emerged from the data. While the prior participant comments are encouraging, after presenting the pictorial creation process it would be beneficial to do additional applied, think aloud problems to determine the effects (or range of effects) of the process on the participants. The acknowledgement of this process raised several questions:

1. Was the process useful to all pictorial problems, or just specific types?
2. Did the process cause the student to be more efficient or effective and to what degree?
3. Did the process help the students develop their spatial skills to a point where the process is no longer needed or is used less?
4. Are there other alternative, part-dependent processes that HSPs used?
5. With refinement, could the pictorial drawing process affect all LSPs?

These are just some of the questions that future studies should investigate. Nevertheless, the emergence of this process seemed to be an important finding in this study and has several implications for teaching, as discussed in the next chapter.

5.1.5. Feelings

The final theme that emerged through both ability groups related to feelings they exhibited. As mentioned in Chapter 4, the HSPs exuded confidence overall, but they also acknowledged other feelings. As I analyzed the data, I wrote in my journal the range of feelings that emerged. They included intrigue, interest, frustration, confusion, indifference, humility, challenge, intimidation, and embarrassment.

What was interesting about these was that nearly every participant experienced each of them. However, the extent to which each participant experienced it was related to his or her ability level. My initial inclination was that HSPs would likely not experience intimidation or frustration, but on the contrary, they did experience those, just to a smaller degree than the LSPs.

For example, P02, who appeared to be the strongest in spatial ability, acknowledged on problem 3 that he could see how the object could be intimidating (it was designed to be that way due to all of the hidden lines present in the multiviews). However, his intimidation quickly subsided as he began to talk and think through the problem. P12, on the other hand, was intimidated by problem 2 and her intimidation caused her to shut down mentally. While she acknowledged that she had that tendency, it provides an example of the range of "intimidation" experienced by two participants with varying ability levels.

The relevancy of this is to understand that each emotion is a continuum rather than a binary situation. There is a continuum of frustration, intimidation, confidence and the like and all participants experience some level of each of these emotions when posed with spatial problems. As well, each individual has their own threshold whereby the emotion can either cripple their productivity (in the case if intimidation, frustration, or indifference) or feed it (in the case of intrigue, interest, and confidence).

5.2. Summary

This chapter has described the various themes that emerged from the data analysis. They included the background and characteristics of various ability level groupings, common errors, the approaches and processes demonstrated, and the feelings exhibited and vocalized by the participants. The next chapter will summarize the study and its results, provide implications for teaching, and recommendations for future studies.

CHAPTER 6. SUMMARY, OUTCOMES, AND IMPLICATIONS

This study has delved into the lived experience of students, examining what the spatial ability phenomenon was like from their perspective. Each of the questions addressed was intended to reveal the phenomenon in the hopes of bettering teaching methods, and more importantly, student learning. To conclude this document, this chapter provides a summary of the study; its purpose, questions, significance, and methodology are revisited. The chapter then provides some summative statements concerning the essence of spatial ability and the spatial phenomenon given the data garnered throughout this study and across the perspectives of the high and low spatial ability participants. It concludes with teaching implications and recommendations for future studies.

6.1. Summary of This Study

Over the course of one spring semester, this study engaged students from an introductory engineering course at Purdue University in in-depth interviews, applied tasks and focus groups. Its purpose was to elicit, describe, and analyze the background, life experiences, and perspectives of individuals with varying levels of spatial ability, answering the question, "What was it like for a student to experience the spatial ability phenomenon?" I believed that understanding the student perspective and experience of the spatial phenomenon would lead to insights into the potential reasons for strength or weakness in visualization and a greater understanding about appropriate spatial ability learning interventions.

6.1.1. Research Questions

The questions central to this research were:

1. What do students report as their personal background (gender, parental occupation, parental involvement, or family income) that could have contributed to their strength or weakness in spatial ability?
2. What personal experiences (hobbies and childhood or teenage experiences) or academic experiences (favorite courses, teachers or subjects) have contributed to their ability or inability?
3. How do students approach spatial activities given their level of spatial ability, that is, what are their attitudes, thought processes, and perceptions surrounding such activities?

6.1.2. Significance of This Study

Based on an extensive literature review, I found that little attention had focused on understanding spatial ability through the qualitative lens. Instead, the expansive literature has used a quantitative approach almost exclusively. Through psychometric, developmental, differential, and information processing means, researchers have defined the composition of spatial ability, how it develops, what is (and is not) correlated with it, individual and group differences in its manifestation, methods for measuring and improving it, as well as the cognitive processes that are the basis for it. Yet, no one appeared to address it directly through the use of qualitative methodologies.

Because of this and the nature of the questions I posed, I chose to use a phenomenological approach in my investigation. I believed that by approaching spatial ability phenomenon this way, I could better understand what high and low spatial ability students perceived when presented with spatial problems. Naturalist inquiry offered a different perspective. Rather than striving to create an intervention and determine its impact, this study focused on the students and elicited their thoughts about their own spatial ability. It is hoped that the insights contained in this study will help all of us better design, develop, and evaluate spatial ability interventions and methods of teaching it to our students.

6.1.3. Methodology of This Study

This research used the tools of qualitative research methodology in the form of interviews, observations, applied tasks, and focus groups. It was founded upon the phenomenological perspective. As a mode of inquiry, phenomenology examines participant experiences and their meanings in the search for an understanding of everyday phenomenal experiences (Van Manen, 1990). Its primary focus is "to explore how human beings make sense of experience and transform experience into consciousness, both individually and as shared meaning" (Patton, 2002, p. 104).

6.1.4. Data Analysis

Using the phenomenological framework, the similarities and differences in lived experiences between those classified as high and low in spatial ability were examined. The data analysis for this study was based upon Giorgi’s procedural recommendations (1985, 1997). Transcripts from each data source were examined and reduced to statements which related to spatial experience. The reduced statements were then examined for emergent, invariant themes. As themes emerged across data sources, they were coded or labeled based on similarities or differences.

6.1.5. Invariant Themes

Through the data analysis five themes emerged from the data. These included common background and experiences of participants, characteristics or tendencies of those who were high and low spatial ability, common errors made in spatial sketching tasks, approaches and processes relative to spatial problem solving activities, and feelings that were expressed or observed in the participants relative to spatial tasks.

6.2. What Is the Essence of Spatial Ability?

Based on the descriptions given by participants, the overarching essence of the spatial phenomenon is using the mind to imagine or picture something, for the purpose of reinterpreting and communicating information about that something in another form (most often, visually). Manifestations of spatial ability are exhibited in either describing anew a pre-existing something or providing visual representations of something such that others can properly understand the nuances of it.

While spatial ability is oft described in myriad ways, the nature of this study examined it within the context of engineering drawing, specifically the creation of multiview drawings from isometric pictorials and vice versa. As acknowledged by the participants, within these applied spatial tasks there are two parts to successfully solving them. The first is the ability to spatially interpret the given problem, that is, to understand it. In understanding it, one is required to mentally picture the object, either wholly or in a piecemeal fashion. As the complexity of an object increases, the latter nearly becomes the required and only approach.

When object complexity surpasses the individual mind's capacity to retain it, the observer must decompose the object, imagining only a piece at a time and then, somehow, aggregate the pieces back into the original whole. Therefore, a skill of import in such problems is the ability to decompose the object and imagine mentally-representable chunks of it, without fear or frustration because one cannot see the entirety of the object. This latter point is of importance for stress, anxiety, frustration, and exhaustion counteract the mind's picturing abilities. Nevertheless, critical to the mental representation of complex objects is one's ability to deconstruct complex spatial problems.

The second part of problem solving is the procedural method or process whereby one transfers the mental image to the traditional page. While someone may be able to picture an object in the mind, reproducing it through sketching is a wholly different matter. Many of the participants acknowledged being able to see the object, but questioned their skills for drawing it. All students could sketch the multiviews and all had a process that had been presented in the course for doing so. That many of the participants could not do the pictorials was not surprising. Most acknowledged that they had no process for getting a pictorial representation from their mind to the page. Given the pictorial drawing process that emerged in this study, they could then understand, "Oh, that’s how you do that."

We must realize that spatial ability and sketching are two different things, even though we often use the latter as evidence of the former. Spatial ability can be developed, although some would argue or take issue with such a statement. In this study, the improvement in MRT scores seemed to provide evidence that spatial ability can be improved. Maybe it is not really an ability at all then, seeing that it can be improved when processes are given and one knows how to use them. Granted, there is a mental capacity to deal with spatial material as the information processing researchers have elaborated, but what if an increase in mental capacity is not what we are talking about? Maybe it is methods, processes, and approaches, instead, that low visualizers actually need, such that they can use the mental capacity that they already have. It appears they have no structuring, no scaffolding, and no mental widgets with which to build or process a visual or mental image. They simply don’t know how to use their spatial capacity and, like many human capacities, that which goes unused seems to slowly wither away or, through disuse, remains undeveloped.

I am reminded of P03, who was classified as a high ability individual. He said that at the beginning of the first day of the class he could only see lines, but by the end of the class he could see objects. Similar statements were made by P07, P09, P10, and P12. Once they had the processes they needed, it appeared that the "ability" (or capacity) was there. What if we need to arm low visualizers with spatial processes and approaches similar to the processes and approaches we provide them for sketching? These are intriguing and valid questions, I believe, in the light of this study.

Based on this research I would argue that spatial ability, specifically the ability to visualize or rotate an object pictured in the mind, is a skill that can be learned rather than an ability that is either present or absent. Many of the low ability participants claimed that they could see the object in their mind but were concerned with getting the object to the page. Once given a process for drawing, however, it appeared that indeed they could see the object because they were then able to sketch it (the evidence we use for the presence of spatial ability). And, those that could not see the object at all, given proper processes for decomposing the objects, claimed they could indeed then see the object (although they then needed an additional process for sketching to get it from brain to paper).

While I present these thoughts, I acknowledge a caution to such simple conclusions. Indeed, all of these students, as acknowledged in Chapters 1 and 3, are enrolled in an introductory engineering course. It probable that because they have self-selected into a course (or major) in which spatial ability is highly desirable and needed that they indeed have this ability that we call spatial ability, whether exercised or not. I acknowledge that for the prior statements to have merit (e.g., that the spatial skills of rotation and visualization are skills, just like sketching) future studies should include a sample that is representative of the human population at large. For these statements to have true credence, a study such as this one should sample not only technically-oriented students, but also non-technical students such as liberal arts, education, or humanities. Nevertheless, in this regard, this study seems to provide a very obvious next step in investigating spatial ability from the qualitative approach.

6.3. What is it like to be Posed with Spatial Problems?

As a major question of this study, for students, what is it like for them to encounter spatial problems? Uniquely, there is a dualism in the feelings that all of the participants encounter. It is frustrating, confusing, challenging, intimidating and at times, embarrassing. However, at the same time it is intriguing and interesting. The various "feelings" of "what it was like" were all experienced, albeit to various levels and at various times.

As mentioned throughout this contribution, overall high visualizers were confident in their abilities, whereas low visualizers often were not. However, we should recognize that all students experienced an entire range of feelings when posed with spatial problems. When initially posed with a difficult problem, it is just as likely that a high visualizer will experience feelings of frustration, confusion, challenge, and intimidation as low visualizers. The difference is the extent of these feelings. It appears that participants of both ability levels start with some measure of these feelings and then are drawn to either the positive side of the "confidence continuum" or the negative side. In the participant think aloud narratives, it was evident that because high visualizers could dissect the problem and had processes to support both dissection and drawing of it, they were drawn to the positive side of confidence. The low visualizers, on the other hand, would gravitate toward the negative end of the "confidence continuum" because they lacked skills for decomposing objects and skills in drawing. A participant’s final destination on the continuum partially depended upon whether they had processes for decomposing the object. Participants who could neither visualize nor understand how to draw the object, arrived at the lowest levels of confidence. Participants who could "see it in their mind" but questioned drawing it, where somewhat higher on that continuum.

The important aspect to note relative to "what it is like" when posed with spatial problems is that feelings play a large role and there is no single feeling amongst either group. They all experienced some "negative" feelings (confusion, intimidation, et cetera), but whether or not they had methods and processes for solving the problems determined the degree to which they experienced these feelings and whether their confidence increased or decreased.

6.4. Implications for Teaching

As noted in Chapter 5, helping students understand how to decompose spatial problems and teaching students to use the pictorial drawing process should be integrated into instruction on creating pictorials from multiview drawings. Likely, the discovery of these was the most important contribution to emerge from this study. It was definitely the biggest ah-ha moment for me during the course of this investigation.

However, while the participants acknowledged that the course did not provide methods for deconstruction or a process for pictorial drawing, they did acknowledge several instructionally effective things in the course that are worthy of mention. They particularly noted two things that were beneficial to them in the course.

First, the method for creating multiviews taught in the course was effective, as evidenced by the participants' ability to solve the multiview creation problem in interview 2. High and low ability students alike acknowledged that they used the process taught in the course and that it was generally effective for them. That several of them acknowledged changing or modifying this process slightly depending on the problem was not surprising. In fact, this acknowledged higher-level thinking in that they were adapting the process presented in the course based upon the problem. Important aspects of this process included:

1. Encouraging students to think in generally directionally-relative terms related to the object (front of object, back of object, right side of object, and so on).
2. The creation of construction boxes (to contain the entirety of the object view) for all of views.
3. The creation of the boundary of the object in each view.

4. Following boundary creation, drawing the features internal to the boundary in each view, saving inclined or oblique surfaces for last.
5. The use of labeling techniques when having difficulty finding oblique or inclined surfaces.
6. The creation of negative geometry (dashed lines) after all positive geometry has been created.
7. A final review of each view compared to one another and compared to the stimulus pictorial.

As acknowledged in Chapter 5, one of the tendencies of high visualizers was that they frequently looked across views, versus low visualizers who did this less frequently. This could impact teaching in that students should be directed to look across views more. In fact, the creation of assignments or exercises (such as multiview completion exercises, where one or more views are missing lines) might be a way to train students to do this.

The second item that students mentioned was the mentored sketching sessions that occurred in the course. The mentored sketch sessions required that the students draw (in class) the solution to various problems in real time with the instructor. Students acknowledged that this helped in several ways. First, the mentored sketching helped the students see (in real time) how to think and to approach spatial problems. It also helped them learn terminology and have a realistic understanding, systematically, of how to accomplish the tasks. The mentored sketches also provided the students an example that they could refer to if they had trouble solving their homework problems; the mentored sketches would do problems similar (but not the same as) their homework problems.

In summary, teaching implications from this study include:

1. Students should be taught (directly in class, via homework, or both) how to deconstruct spatial pictorial problems.

2. Students should be taught the pictorial drawing process described in Chapter 5, with representative homework problems on which they can practice.
3. Students should be taught the multiview drawing process described above, with representative homework problems on which they can practice.
4. As part of the instructional approach, engineering design drawing courses should utilize mentored sketching as part of the in-class assignments that students execute.

6.5. Recommendations for Future Studies

As with any study, hindsight points to many things that could have been done differently or better. The following are acknowledgements of these.

Further investigation into play activities with Legos. As noted, the literature suggests that play activities with Legos and other physical toys are related to exhibited spatial ability in various forms. Future qualitative studies such as this one should indeed investigate further details surrounding play activities with Legos (or other hands-on toys) to understand better the potential relationship with spatial ability development. Knowing more about frequency of play, length of time, and method of play might provide a richer understanding in this area.

Further investigation into the role of mathematics experience. Future qualitative studies similar to this one might want to provide some method of following up or delving more deeply into the subject of mathematics experience and performance.

Focus an entire study on the role of visualization in sports performance. As acknowledged in Chapter 5, surprising to me were the detailed accounts of visualization and its effect on sports performance. During my literature review I found no studies that examined this. Understanding how sports visualization works may yield important insights into spatial ability, but it is also intriguing in its own right as well.

Do more applied exercises. Due to the time limitations in this study, I was unable to have the low ability students do more pictorial problems after showing them the pictorial drawing process. Evidence in this study relative to the impact of the pictorial draw process was based on participants reporting that it was invaluable to them on the sketch exam that followed interview 2. Future studies could potentially have the students do a pictorial drawing without the aid of the pictorial process and then do one with it to see its impact.

Investigate further strategies for 2D and 3D object decomposition. As acknowledge in Chapter 5, object decomposition is important for students to be able to visualize. There is much to be explored in how students decompose objects, various methods for doing so, and the efficiencies of them.

Investigate why the pictorial drawing process helped low ability learners. Quite possibly the most intriguing question for me was the "why" associated with the pictorial drawing process. Why had students not thought about the sketching process in the way that emerged in the study? It was evident that the high visualizers were using this process. Why were they aware of it?

While these are likely only some questions that come to the minds of readers of this work, they are ones that have littered my observation journal as I have observed, transcribed, and analyzed the data from this study. It seems as though this study, while providing useful insights into the essence of spatial ability, has raised only more questions that my curiosity desires to answer. However, of greater significance was experiencing the spatial phenomenon anew with the participants of this study. As the acclaimed fiction writer Doris Lessing stated:

> That is what learning is. You suddenly understand something you've understood all your life, but in a new way.

6.6. Summary

This chapter has concluded the documentation of this study by revisiting the major endeavors that were a part of it. This chapter also presented holistic answers to the primary questions posed at the beginning of the study. It is hoped that the reader now has an understanding and appreciation for what it is like to experience the spatial phenomenon. Yet, of greater importance to me are the summary of teaching implications. In my opinion, all research is in vain if it sequesters only knowledge that is impractical to the everyday lives of humanity. Thus, the section on teaching provides several statements relative to how we as teachers in our various disciplines might better teach our students to use their spatial ability. Finally, the concluding section of the chapter has provided recommendations for future studies. It is hoped that this might be only one of many studies that emerge in the future, examining spatial ability from the qualitative perspective.

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APPENDICES

Appendix A. Vandenberg Mental Rotations Test

Mental Rotations Test[2]
Spring 2006

This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles. Figure 1 demonstrates this principle, where the same object is given in five different positions. Look at each of them to satisfy yourself that they are the same object presented at different angles.

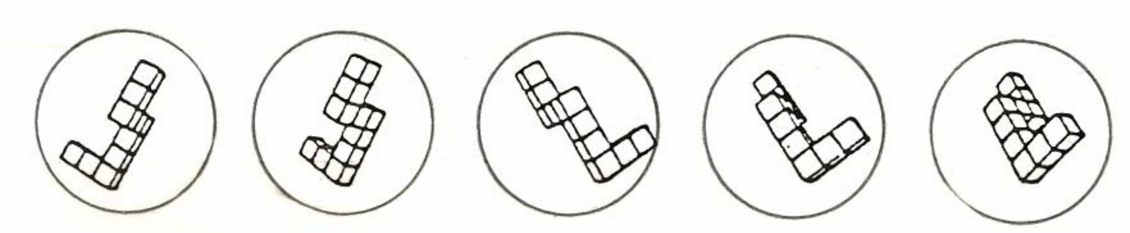

Figure 1. The same object in different positions

Figure 2 shows two drawings of a new object that cannot be made to match the object depicted in Figure 1. Please note you may not turn over the objects. Satisfy yourself that the object depicted in Figure 2 are different from the object depicted in Figure 1.

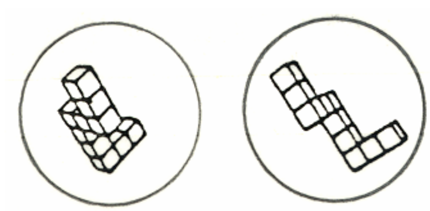

Figure 2. Two drawings of a new object

Now let's do some sample problems. As shown in Figure 3, for each problem there is a primary object on the far left. You are to determine which of the four objects to the right are the same object given on the far left. In each problem always two of the four drawings are the same object as the one on the left. You are to choose the correct ones. The first sample problem is done for you.

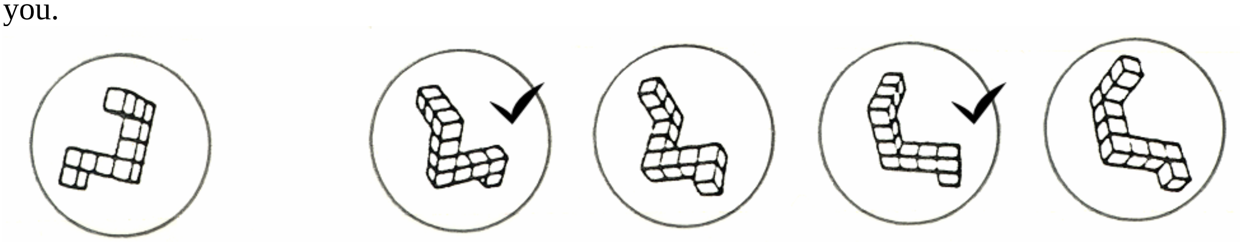

Figure 3. A sample problem with the correct drawings marked.

GO TO THE NEXT PAGE =>

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[2] Adapted by S. G. Vandenburg, University of Colorado, July 15, 1971. Revised instructions by H. Crawford, University of Wyoming, September, 1979, by G. R. Bertoline & C. L. Miller, The Ohio State University, September, 1987, and J. L. Mohler, Purdue University, 2006.

Do the rest of the sample problems yourself (see Figure 4). Which two drawings of the four on the right show the same object as the one on the left? There are always two and only two correct answers for each problem.

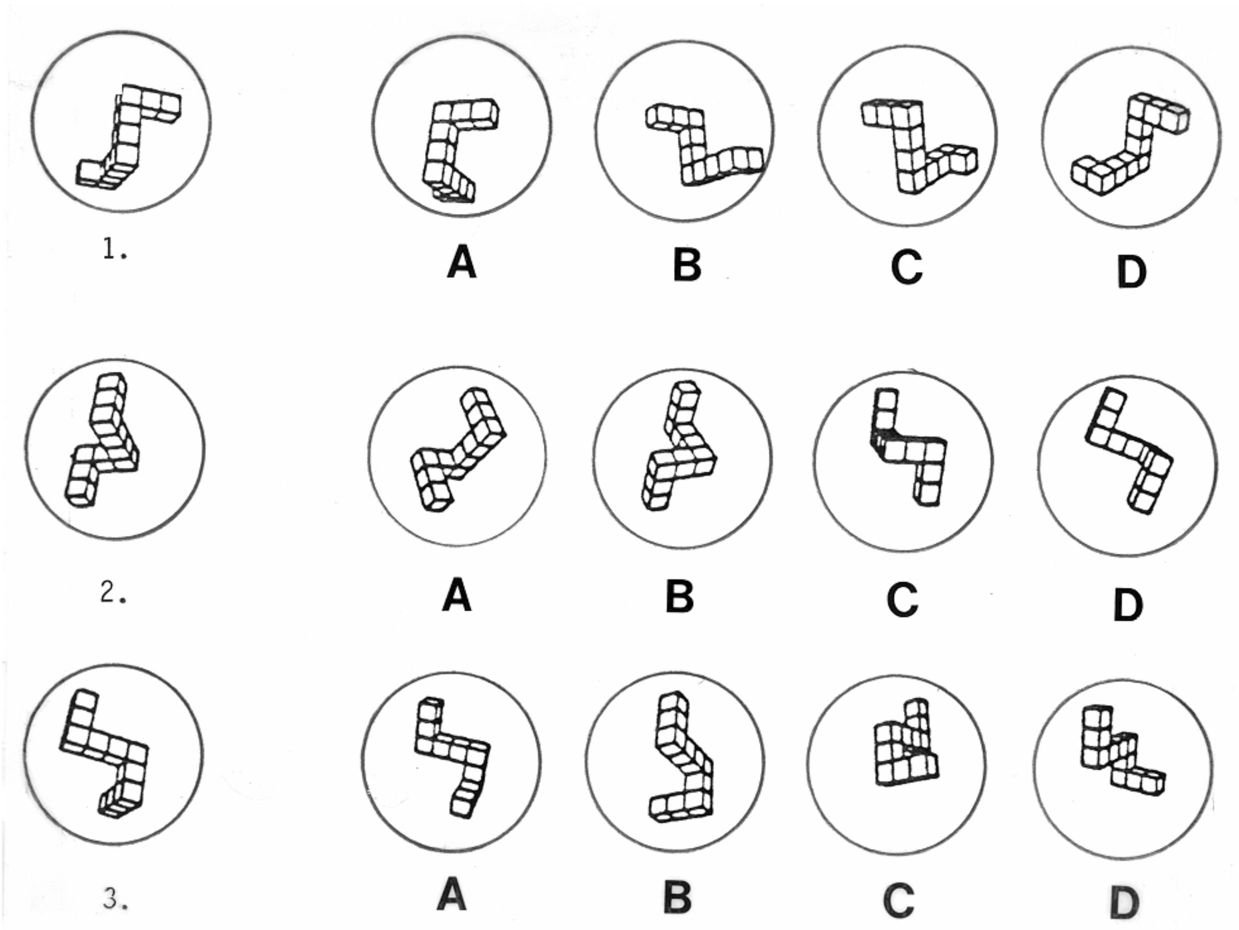


Figure 4. Sample problems to be solved.

Answers:	(1)	A & B
	(2)	A & C
	(3)	B & C

This test has two parts. You will have **10 minutes** for each of the two parts. Each part has two pages. When you have finished Part I, **STOP**. Please do not go on to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

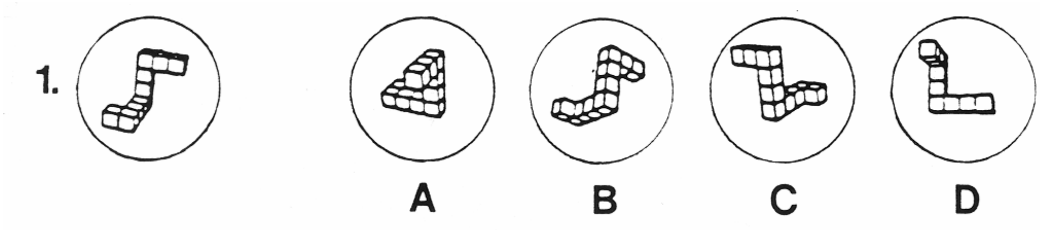
Work as quickly as you can without sacrificing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.

On the scantron answer sheet, use items 1 through 10 for Part I of the test. For Part 2, start with number 11 and end with number 20. Use only a soft, black lead pencil.

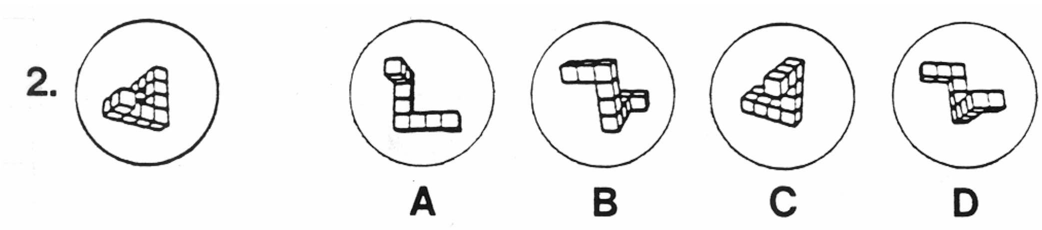
DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO

Part 1

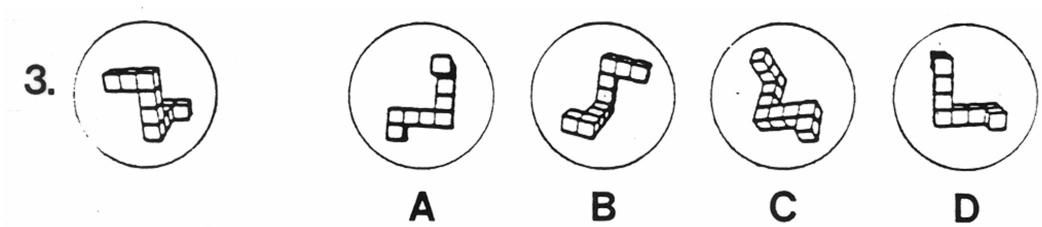
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D



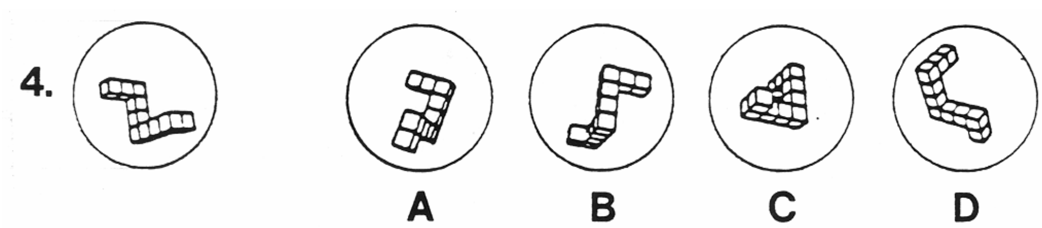
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D



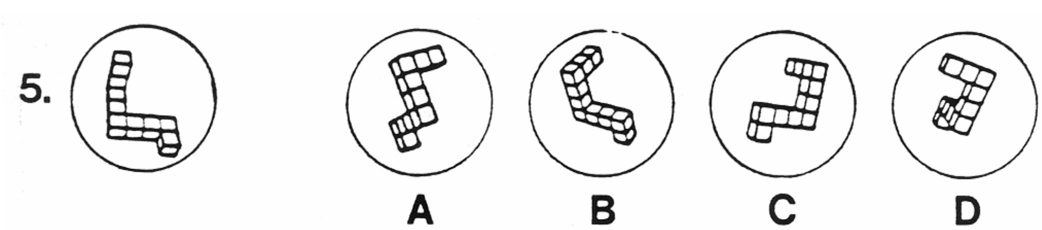
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D



1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D



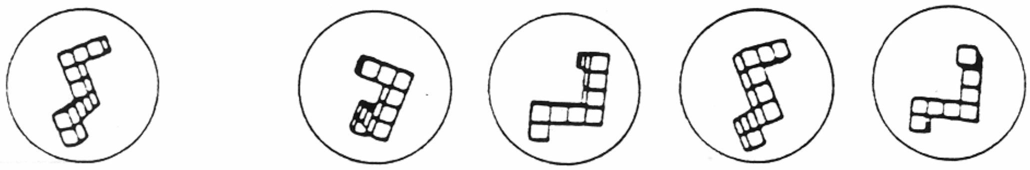
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D



TURN THE PAGE AND CONTINUE

1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

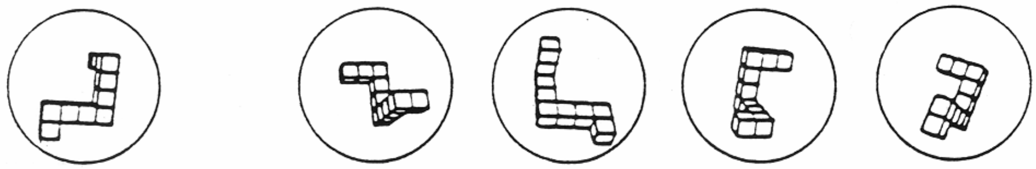
6.



A B C D

1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

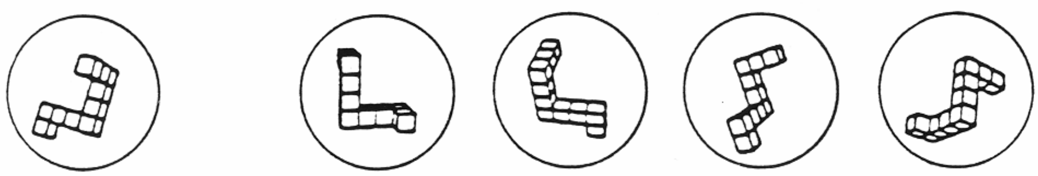
7.



A B C D

1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

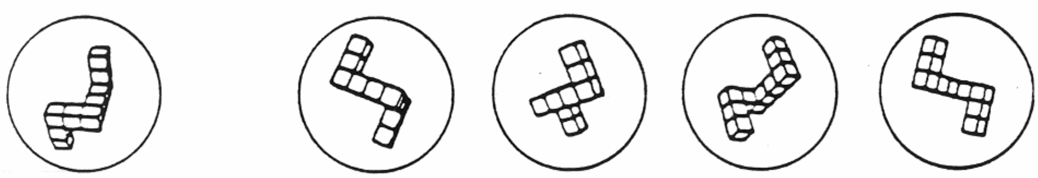
8.



A B C D

1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

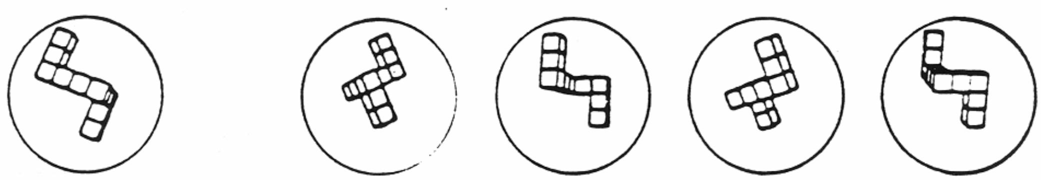
9.



A B C D

1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

10.



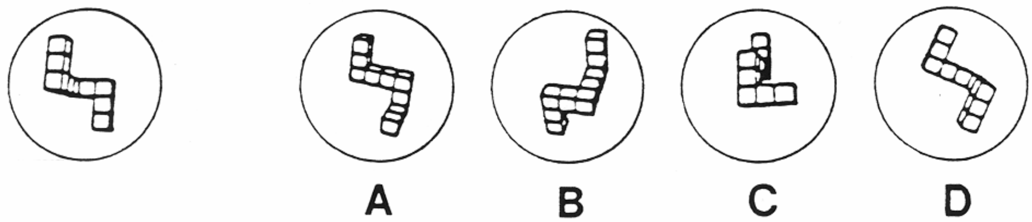
A B C D

<u>STOP. Do not turn the page.</u>

Part 2

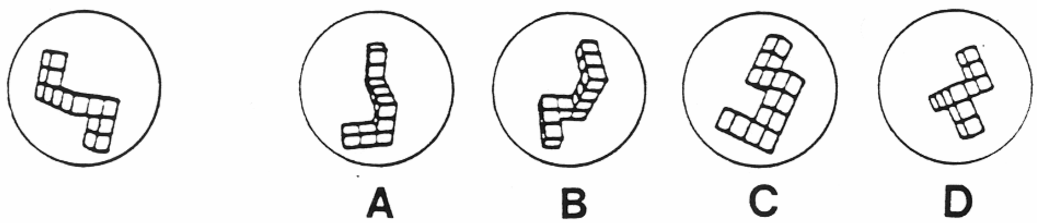
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

11.



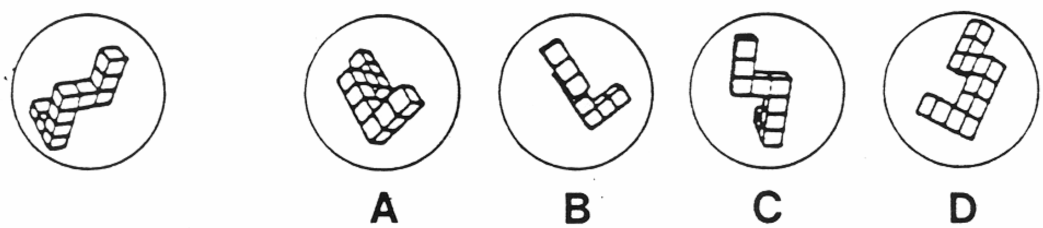
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

12.



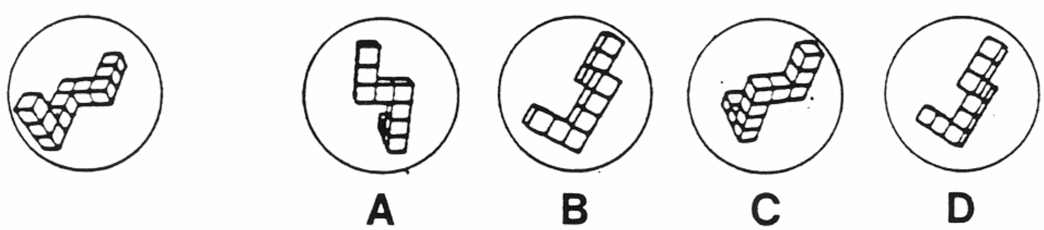
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

13.



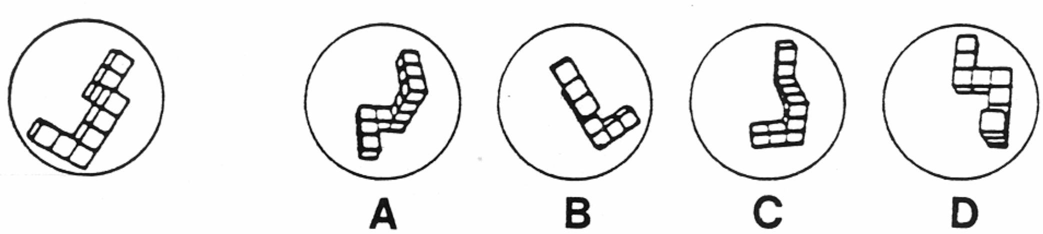
1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

14.



1 = A & B
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

15.



Turn the page and continue

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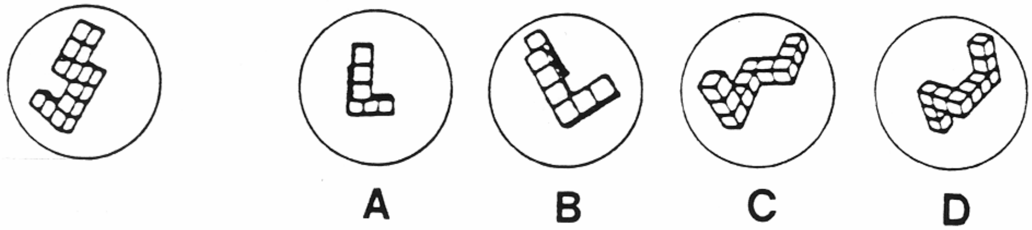
2 = A & C
3 = A & D
4 = B & C
5 = B & D
6 = C & D

16.



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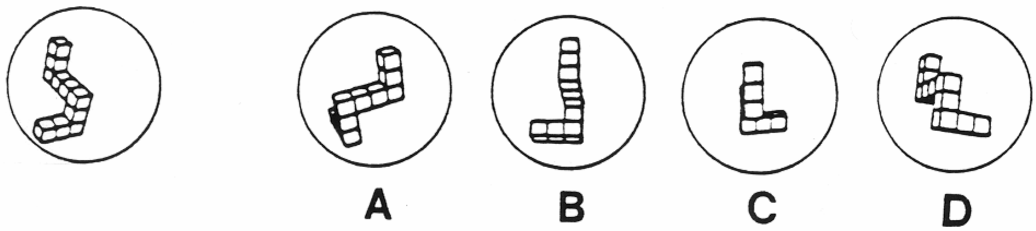
3 = A & D
4 = B & C
5 = B & D
6 = C & D

17.



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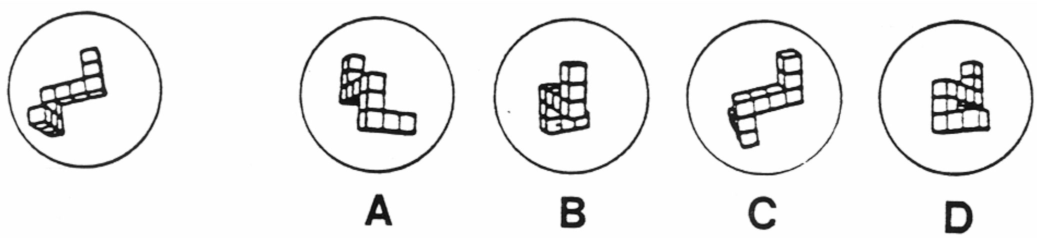
3 = A & D
4 = B & C
5 = B & D
6 = C & D

18.



1 = A & B
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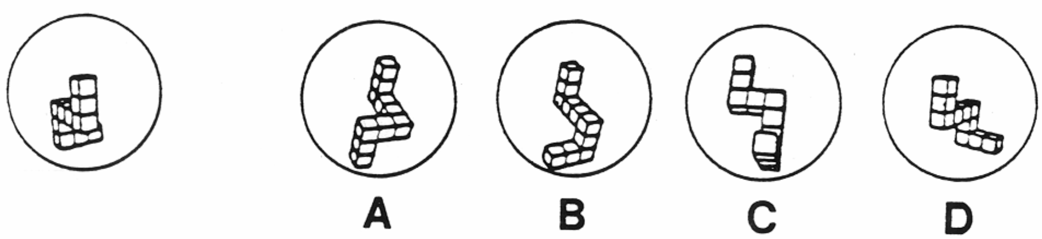
3 = A & D
4 = B & C
5 = B & D
6 = C & D

19.



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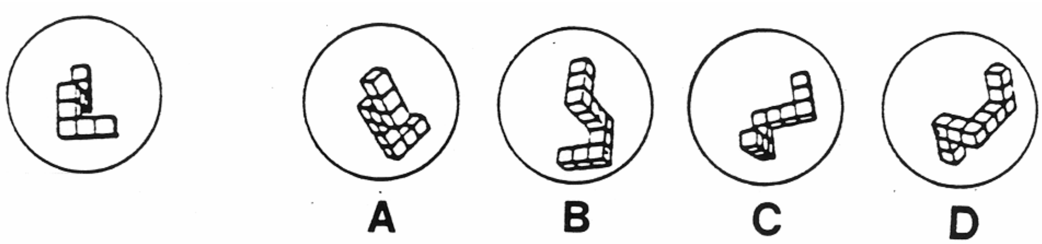
3 = A & D
4 = B & C
5 = B & D
6 = C & D

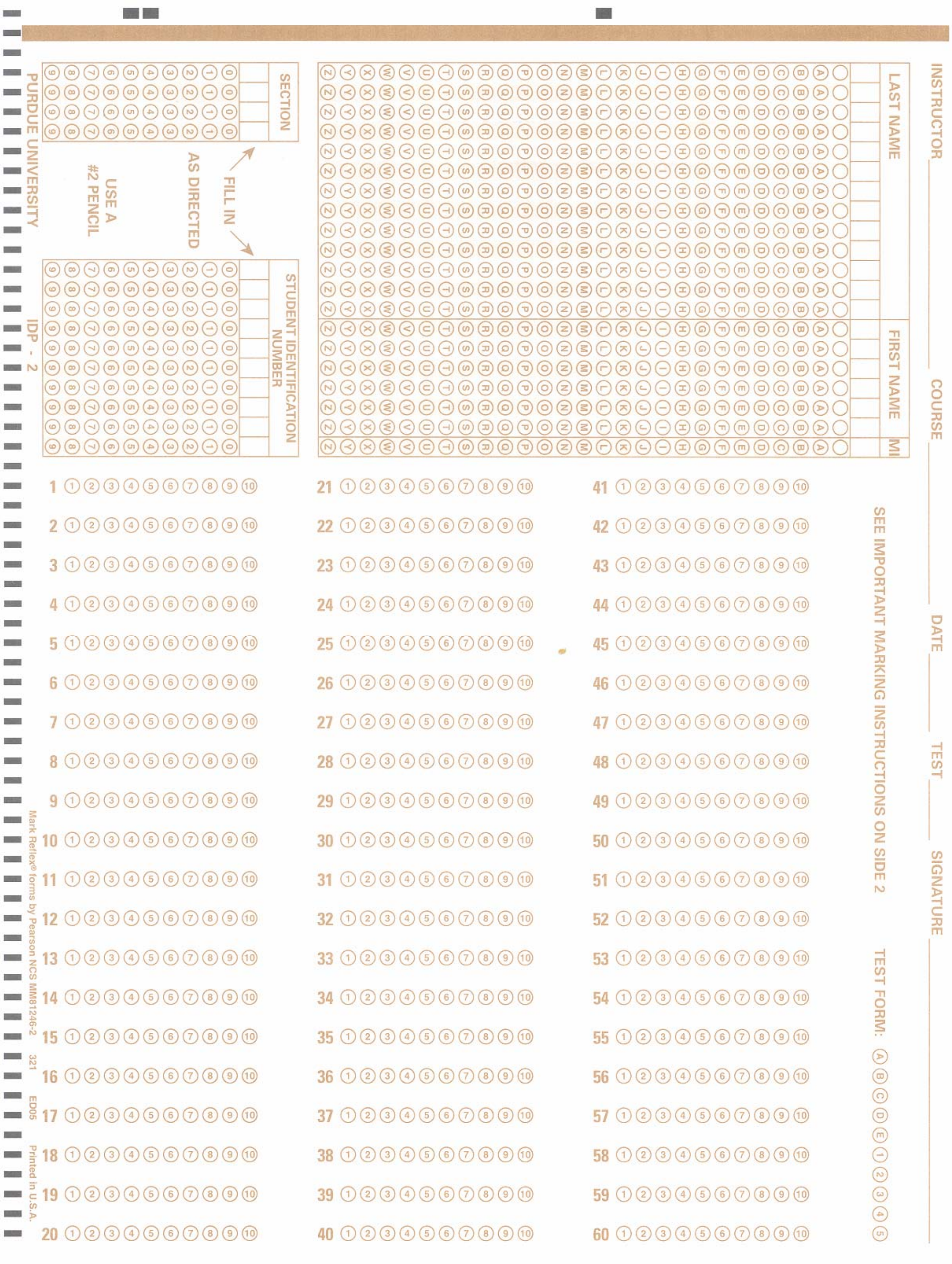
20.



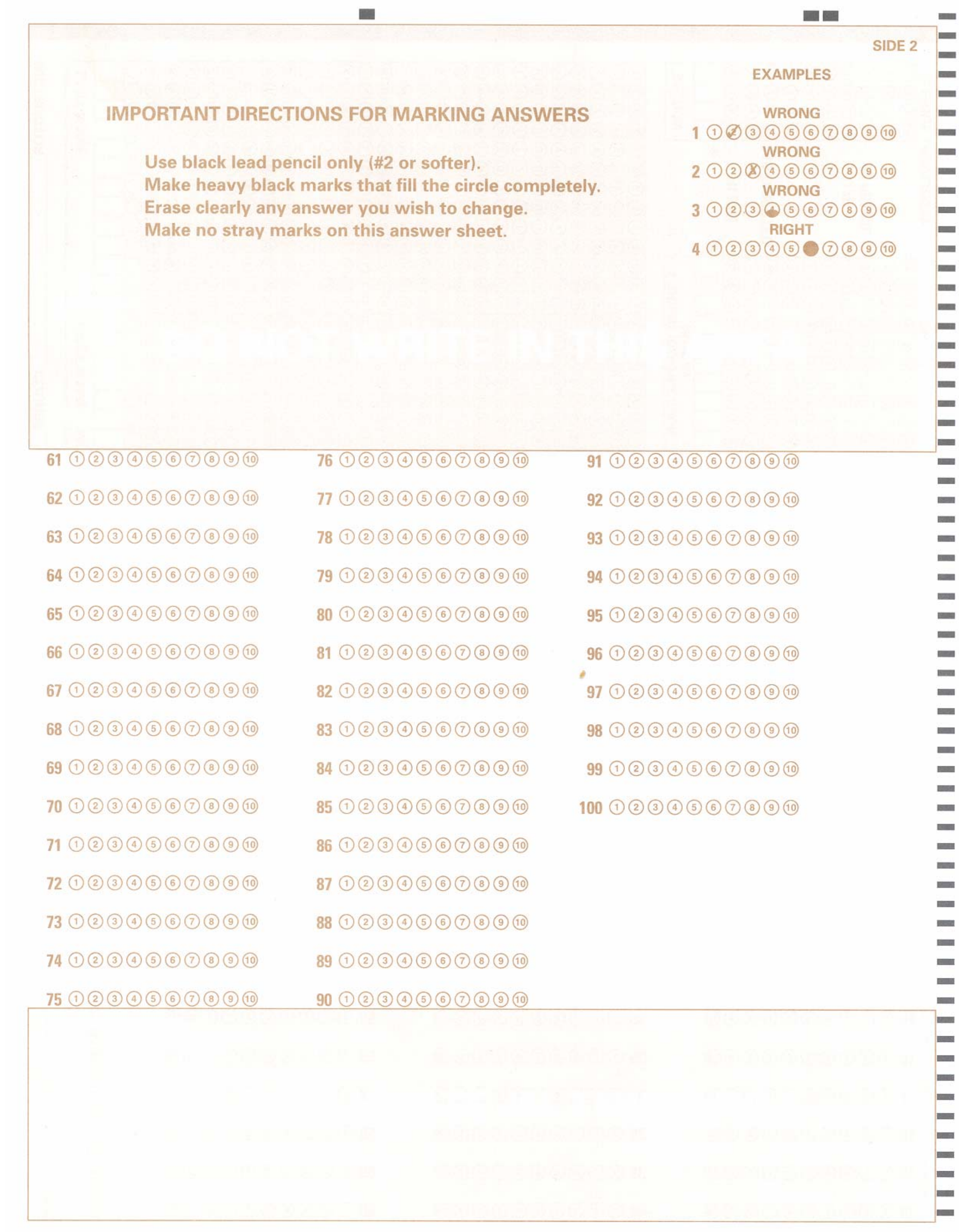
<u>Stop. Please turn in your booklet and scantron sheet.</u>

Appendix B. Scantron Answer Sheet

Front of Scantron



Back of Scantron



SIDE 2

IMPORTANT DIRECTIONS FOR MARKING ANSWERS

Use black lead pencil only (#2 or softer).
Make heavy black marks that fill the circle completely.
Erase clearly any answer you wish to change.
Make no stray marks on this answer sheet.

EXAMPLES

WRONG
1 ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
WRONG
2 ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
WRONG
3 ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩
RIGHT
4 ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

61–100 ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

Appendix C. Background Questionnaire

Background Questionnaire

Thank your for participating in this study. As you fill out the questionnaire below, please answer all questions and provide as much information as possible in those asking for written answers.

Name: ______________________________ Prefer to go by: ______________

Age: ____________________ Email: ____________________

Phone: ____________________ Gender: Male ☐ Female ☐ Handedness: Right-handed ☐ Left-handed ☐

Parental Occupations:
Father: ____________________
Mother: ____________________

Parental involvement in your education:
Uninvolved ☐ Slightly Involved ☐ Involved ☐ Moderately Involved ☐ Very Involved ☐

Ethnicity:
African ☐ Asian/Pacific Islander ☐ Caucasian ☐ Hispanic ☐ Native American ☐ Other ☐ Please Specify:____________

Family Income:
Less than 30,000 ☐ 30,001-60,000 ☐ 60,001-90,000 ☐ 90,001-120,000 ☐ 120,001-150,000 ☐ 150,001-180,000 ☐ 180,001-210,000 ☐ 210,001-240,000 ☐ Greater than 240,001 ☐

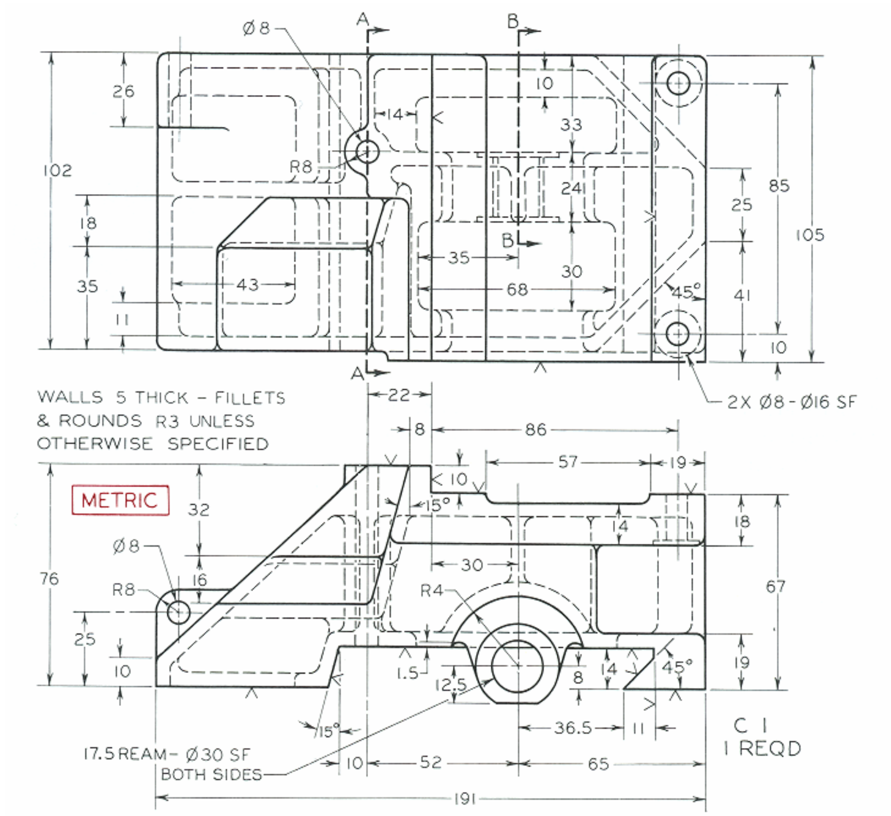
Do you play a musical instrument?	YES ☐	NO ☐
Do you like to read books?	YES ☐	NO ☐
Do you like to write (poetry, stories, etc)?	YES ☐	NO ☐
Would you consider yourself strong in math?	YES ☐	NO ☐
Would you consider yourself strong in programming?	YES ☐	NO ☐

Educational Background: ______________________________

Hobbies: ______________________________

Favorites Subjects in School: ______________________________

Appendix D. CGT 163 Extra Credit Problem



*Giesecke, F. E., et.al (1993). Engineering Graphics, MacMillan Publishing Company, New York

Support Base:

Given the dimensioned front and top views of the Support Base construct a 3D solid model in CATIA V5 R14. 50 assignment points extra credit.

NOTE: You will be entire responsible for this model. NO extra instructional help will be provided by the CGT 163 instructors.

Due date: End of laboratory week 16.

Appendix E. Consent Form

Attachment F: Research Participant Consent Form

05100030 65

A QUALITATIVE STUDY EXAMINING THE SPATIAL ABILITY PHENOMENON
FROM THE STUDENT'S PERSPECTIVE

Timothy J. Newby, Ph.D.
Purdue University
Curriculum and Instruction

Purpose of Research

The purpose of this research is to describe and analyze the background, experiences and perspective of individuals with varying levels of spatial ability; leading to better insight into the potential reasons for strength or weakness in visualization and a better understanding about appropriate spatial ability interventions.

Specific Procedures to be Used

All participants will fill out a brief questionnaire to provide background information about themselves and will participate in one 1-hour focus group session. Six participants will also have three semi-structured interviews lasting 90 minutes spread throughout the spring semester. These will be conducted in a faculty office in Knoy Hall outside of regularly scheduled class times to garner background, perspectives, attitudes and approaches to spatial problems. The interview and focus group sessions will be tape recorded and transcribed, with the tapes being subsequently destroyed within two weeks. Information identifying the subjects will only be used to match test scores and response and will subsequently be replaced with random participant numbers.

Duration of Participation

Six students will participate in three 90 minute interviews and one 1 hour focus group meeting.
Six students will be observed in three class sessions and participate in one 1 hour focus group meeting.

Benefits to the Individual

Participation in this study may provide benefits in helping you understand your mental processes and why your spatial ability is developed to the degree that it is (as well as reveal ways in which you may develop this skill further).

Risks to the Individual

The risks of participating in this study are minimal and no more than the you would encounter in everyday life.

Confidentiality

All of your responses (verbal and written) will be recorded and transcribed for analysis. After matching such data, each student's information will be assigned a random participant number so that your identity will not be known. Transcribed data will be retained indefinitely. Due to the use of focus groups, it cannot be guaranteed that other members of the focus group will maintain confidentiality.

Voluntary Nature of Participation

You do not have to participate in this research project. If you agree to participate you can withdraw your participation at any time without penalty (and any data or information you provided will be destroyed).

Human Subject Statement:

If you have any questions about this research project, you can contact Dr. Timothy Newby (49-45672). If you have concerns about the treatment of research participants, you can contact the Committee on the Use of Human Research Subjects at Purdue University, 610 Purdue Mall, Hovde Hall Room 307, West Lafayette, IN 47907-2040. The phone number for the Committee's secretary is (765) 494-5942. The email address is irb@purdue.edu.

I HAVE HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE RESEARCH PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

_______________________ Participant's Signature   _____________ Date

_______________________ Participant's Name

_______________________ Researcher's Signature   _____________ Date

APPROVED
NOV 09 2005
EXPIRES 11/8/06
PURDUE UNIVERSITY
INSTITUTIONAL REVIEW BOARD

Appendix F. Example Email Invitation

Hello (name),

Recently you expressed an interest (either via email or by sign-up sheet) a desire to be involved with the research project I am doing with students in CGT 163. If you are still interested in participating, you have been selected as a participant that will:

- Be involved in three 90-minute interviews over the next 2 months (February and March)
- Be involved in one 1-hour focus group meeting (with six other participants) in April

If you are still interested in participating, please reply to this email. Once I have received an email from you we will work towards scheduling the first interview and I will also notify Professor Miller or Wittenborn of your selection and agreement to participate.

I would like the interviews and focus group meeting to occur during the following time periods:

- Interview 1 (weeks 5 & 6; Feb. 6th thru Feb. 17th)
- Interview 2 (weeks 7 & 8; Feb. 20th thru Mar. 2nd)
- Interview 3 (weeks 11 & 12; Mar. 20th thru Mar. 31st)
- Focus group meeting (weeks 13 & 14; Apr 3rd thru Apr 14th)

Thanks again for your interest in this project. Upon receiving your response, I will follow-up with more information.

Sincerely,

James L. Mohler
CGT

Appendix G. Interview Objectives

Interview #1: Personal Background History

I am interested in hearing about your personal background that could have contributed to your strength or weakness in spatial ability. What personal experiences (hobbies and childhood or teenage experiences) or academic experiences (favorite courses, teachers or subjects) have contributed to your ability to visualize?

(During interview #1, I will request that each person fill out a short survey instrument to garner information about gender, handedness, parental occupation, parental involvement, or family income. Then I will probe into the areas that they mention as to either their strength or weakness in the area of spatial ability. This interview will last approximately 90 minutes.)

Interview #2: Approach to Spatial Problems

I am interested in how you approach spatial problem solving in CGT 163. When presented with one of the modeling exercises, how to you get started? How do you prepare? How do you tackle difficulties you encounter to help you get the problem done?

(In this round of interviews, my primary focus will be on how the students approach spatial problems presented in class and how they deal with their own ability or inability to solve them).

Interview #3: Follow-up and Progress Interview

How do students approach spatial activities given their level of spatial ability, that is, what are their attitudes, thought processes and perceptions surrounding such activities?

(This final interview will be used to get the student to check prior interview responses as well as to assess his or her progress – the how and why he or she has progressed or not progressed in spatial ability)

Appendix H. Interview 1 Guide

Interview #1 Guide

(Phone off hook; sign on door, AIM/Skype shut down)

I am interested in hearing about your personal background that could have contributed to your spatial ability. Overall I am interest in learning about any personal experiences (hobbies and childhood or teenage experiences) or academic experiences (favorite courses, teachers or subjects) that could have contributed to your ability to visualize.

Background Questions

When you were a child, were there an experiences you can think of that could have contributed to your spatial ability?

- Toys you played with?
    - Favorite childhood toy?
    - Favorite play activity?
    - Access to “building block” toys?
    - Have access to a computer? What did you use it for?
    - Have access to video games? What type did you play?
    - Physical objects?
    - Mechanical models?
    - Geometric puzzles?
    - Wooden cubes?
- Imagination?
    - Did you have any imaginary friends?
    - Did you create your own games?
    - Did you dress up or other such things?
- Craft hobbies?
    - Construct things (from paper, cardboard, etc)?
    - Art, drawing or color?
    - Build models?
    - Woodworking?
- Listen or play music?
    - Did you at one time play one or more musical instruments?
        - If yes, what instruments?
    - How many years trained to play?
    - Ever a member of a musical group? If yes, describe?
    - Do you sing? How many years trained?
- Mechanical hobbies?
    - Working on cars?
    - Building things?

Growing up, did you have any courses, teachers or subjects that might have impacted your spatial ability?

- Math, science, art, drafting courses?
- Peculiar things teachers had you do that

- Favorite subjects?

Growing up, did you have any courses or particular subjects that were extremely difficult for you?

  - Grammar/spelling/punctuation?
  - Reading or reading comprehension?
  - Speech class?

Did you play sports growing up?

  - What sports?
  - Play in competitions?
  - Visualization a part?

Concerning sleeping habits…

- How often do you remember your dreams?
- Do you have vivid dreams?
- Deja-vu often?

Metacognition Questions

Overall what is your perception of your own spatial ability? Do believe you are strong or weak?

Have you been conscious of your spatial ability? Realized you were visualizing as your were doing it?

Have you ever been frustrated not being able to visualize something? Was there something you did to help you better visualize something?

Applied Question

Now I want to do a short exercise with you. I will give you a brief description of an object and I want you to picture it in your mind and then describe it to me. Try to imagine the object as vividly as you can and try to describe all details of the object, even if you see something in your mind that is not part of my description.

I want you to imagine a table. The table has a oblong top with a pedestal base. It is made of wood and is in “mint condition.”

Describe the table for me.

Appendix I. Interview 2 Guide

Interview #2 Guide

(Phone off hook; sign on door, AIM/Skype shut down)
(Pencils, ortho and iso grid paper available, pencil sharpener nearby)

Instructions
In this interview, I want to see how you approach spatial ability problems (like those you encounter in CGT 163) and watch you solve three different sketching problems. For each problem you will have about one-half an hour.

For each problem, I will give you some brief instructions and a few minutes to study the problem before trying to solve it.

Pre-problem questions
- When I told you we would be doing applied problems for this interview, how did you feel?
- Are you apprehensive about the problems you are getting ready to do?
- Do you think you will have any trouble with the problems?

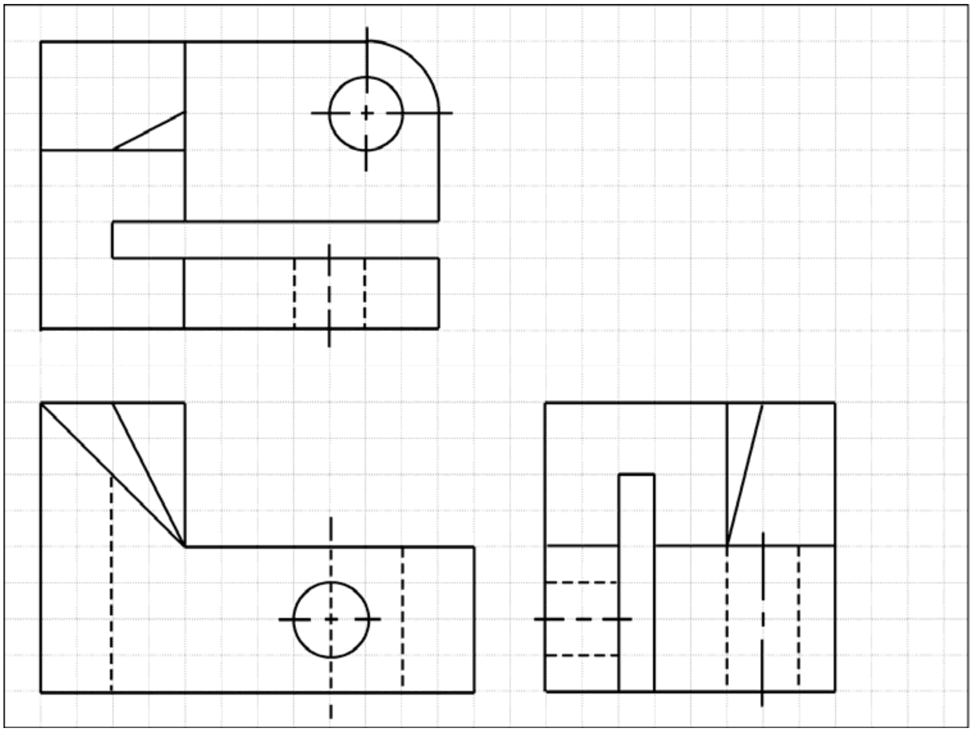
`

First Problem
The goal of this problem is for you to create the appropriate multiview drawings of the object, just like you would in CGT 163. Take a few moments and study the problem but as you do, talk to me about what you are thinking about, what you are looking at, how you are planning to tackle the problem. Then, when you are ready you can start drawing the solution (but again, as you do, talk aloud – absolutely anything you would think or say to yourself).

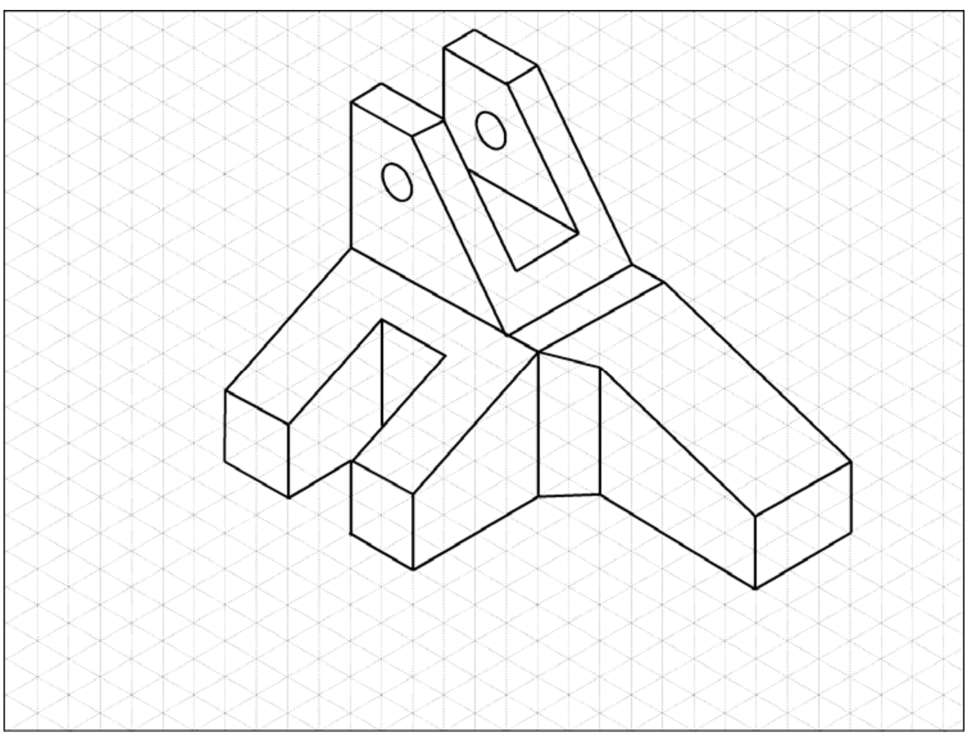
Second Problem
The goal of this problem is for you to create the appropriate pictorial drawing of the object shown by the set of multiviews. Take a few moments and study the problem but as you do, talk to me about what you are thinking about, what you are looking at, how you are planning to tackle the problem. Then, when you are ready you can start drawing the solution (but again, as you do, talk aloud – absolutely anything you would think or say to yourself).

Third Problem
The goal of this problem is for you to create the appropriate pictorial drawing of the object shown by the set of multiviews. However, the object depicted is design to be more complex than the prior two objects you worked with. Take a few moments and study the problem but as you do, talk to me about what you are thinking about, what you are looking at, how you are planning to tackle the problem. Then, when you are ready you can start drawing the solution (but again, as you do, talk aloud – absolutely anything you would think or say to yourself).

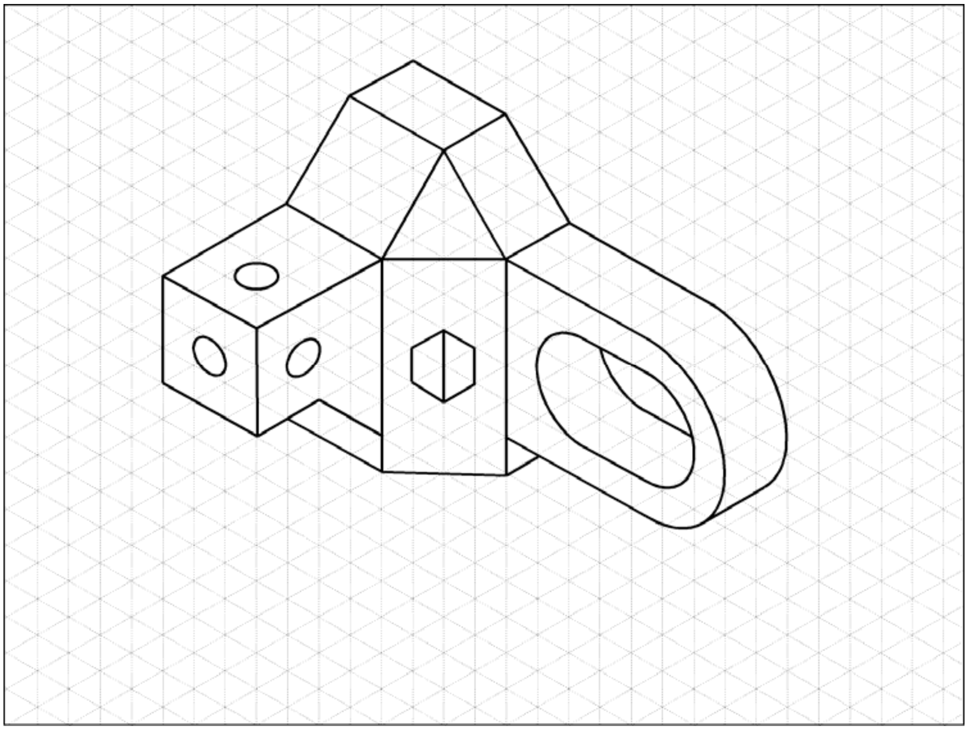
Task 1 Solution



Task 2 Solution



Task 3 Solution



Appendix J. Interview 3 Guide

Interview #3 Guide

(Phone off hook; sign on door, AIM/Skype shut down)

Sketch Exam

1. How do you think you did on the sketching exam? Did you find it easy, moderate or difficult?

2. Do you think it was representative of the sketch assignments you have been doing in the class?

General

1. Given your experiences in CGT 163 and in this study, do you believe you have improved your spatial ability? Why or why not?

2. Do you think there are things that you can do to improve your spatial skills further? If so, what are they?

3. Do you think that your spatial skills will be important to you throughout the rest of your courses at Purdue or in your chosen career field?

Reflection

1. How would you explain to someone else how to visualize the multiviews of an object based on a 3D pictorial?

2. Do you have a general process that you follow religiously when doing multiviews?

3. What advice would you give to someone who is having difficulty visualizing multiviews? What would you suggest they do to help themselves?

4. How would you explain to someone else how to visualize a 3D object based on multiviews of an object?

5. Do you have a general process that you follow religiously when doing multiviews?

6. What advice would you give to someone who is having difficulty visualizing multiviews? What would you suggest they do to help themselves?

Attitudinal

1. How do you feel when you are posed with a spatial problem?

2. Have you enjoyed (as much as is possible) using and/or developing your spatial skills in this course?

3. What has been the most frustrating thing for you concerning the spatial things you have done in the course.

Course

1. What things in CGT 163 have helped you the most in developing your spatial skills?

2. Do you think that the sketching exercises helped you develop your spatial skills?

3. If you could change anything about CGT 163, what would you change, add or delete?

Study

1. Although there is one more meeting (focus group), have you enjoyed participating in this study?

2. Was there anything about the interviews that made you uncomfortable or that you would change?

3. In the first interview we focused on your background and experiences growing up. Since you have had a little time to reflect on it, do you have anything that you would like to add – anything that you might have forgotten that could have affected or contributed to your spatial ability?

4. Did you find that doing the exercises in Interview 2 helped you in preparing for the sketch exam?

5. During the study interviews or during the course, did you have any ‘ah-ha’ experiences (something that “just clicked” or “made sense” to you that didn’t before)?

Appendix K. Focus Group Questions

Focus Group Questions

General

- Given your experiences in CGT 163 and in this study, do you believe you have improved your spatial ability? Why or why not?

- Do you think there are things that you can do to improve your spatial skills further? If so, what are they?

- Do you think that your spatial skills will be important to you throughout the rest of your courses at Purdue or in your chosen career field?

Reflection

- How would you explain to someone else how to visualize the multiviews of an object based on a 3D pictorial?

- Do you have a general process that you follow religiously when doing multiviews?

- What advice would you give to someone who is having difficulty visualizing multiviews? What would you suggest they do to help themselves?

- How would you explain to someone else how to visualize a 3D object based on multiviews of an object?

- Do you have a general process that you follow religiously when doing multiviews?

- What advice would you give to someone who is having difficulty visualizing multiviews? What would you suggest they do to help themselves?

Attitudinal

- How do you feel when you are posed with a spatial problem?

- Have you enjoyed (as much as is possible) using and/or developing your spatial skills in this course?

- What has been the most frustrating thing for you concerning the spatial things you have done in the course.

Appendix L. CGT 163 Instructional Schedule

Department of Computer Graphics Technology

CGT 163 Introduction to Graphics for Manufacturing

Spring Semester 2006

Instructional Schedule

Week 01	Laboratory Prep.	Introduction to the CATIA Interface
1/09	Reading	Miller: Chapter 1
	Theory Lecture	Course Introduction
	Reference	Bertoline: Chapter 1, Pages 1-14 & 29-32,
	Readings	Bertoline: Chapter 2, Pages 37-54 & 62-64
		MRT Test
	Assignment 01	Background Questionnaire
	Assignment 02	ASSIGNMENT DESCRIPTION
	Assignment 03	ASSIGNMENT DESCRIPTION
	Assignment 04	Miller: Exercise 1.1
	Assignment 05	Miller: Exercise 1.2
	Assignment 06	Lecture Sketch – Wednesday – Sketch combination grid sheet
	Assignment 07	1
	CATIA File	PISTON PART
Week 02	Laboratory Prep.	**None: Dr. Martin Luther King, Jr. Memorial Holiday**
1/16	Reading	Miller: Chapter 2
	Theory Lecture	Orthographic Projection Standards and Conventions
	Required Tutorial	MULTIVIEW TUTORIAL
	Reference	Bertoline: Chapter 5, Pages 187-262
	Readings	Miller: Exercise 2.1
	Assignment 08	Miller: Exercise 2.2
	Assignment 09	ASSIGNMENT DESCRIPTION
	Assignment 10	ASSIGNMENT DESCRIPTION
	Assignment 11	ASSIGNMENT DESCRIPTION – Sketch orthographic grid
	Assignment 12	sheet 1
	Assignment 13	ASSIGNMENT DESCRIPTION – Sketch orthographic grid
	Assignment 14	sheet 2
	CATIA Parts	LECTURE SKETCH – Wednesday – Sketch combination grid
		sheet 2
		SAMPLE 1 PART
		SAMPLE 2 PART
		EXTRA CREDIT MODEL
Week 03	Laboratory Prep.	Creating Sketched CAD Geometry
1/23	Reading	Miller: Chapter 3
	Theory Lecture	Multiview Sketching
	Reference	Bertoline: Chapter 2, Pages 77-118
	Readings	ASSIGNMENT DESCRIPTION – Sketch orthographic grid
	Assignment 15	sheet 3
	Assignment 16	ASSIGNMENT DESCRIPTION – Sketch orthographic grid
	Assignment 17	sheet 4
	Assignment 18	Miller: Exercise 3.1

	Assignment 19	Miller: Exercise 3.2 Lecture Sketch – Wednesday – Sketch combination grid sheet 3 **NOTE: Last day to cancel a course assignment without it appearing on record**
Week 04 1/30	Laboratory Prep. Reading Theory Lecture Reference Readings Assignment 20 Assignment 21 Assignment 22 Assignment 23 Assignment 24 Assignment 25	Constraints Miller: Chapter 3 Points, Lines, And Planes Bertoline: Chapter 6, Pages 303-321 SKETCH – AUXILIARY – Sketch orthographic grid sheet 6 SKETCH – AUXILIARY – Sketch orthographic grid sheet 7 Miller: Exercise 3.3 MILLER: EXERCISE 3.4 Miller: Exercise 3.5 Lecture Sketch – Wednesday – Orthographic grid sheet 5
Week 05 2/6	Laboratory Prep. Reading Theory Lecture Reference Readings Assignment 26 Assignment 27 Assignment 28 Assignment 29	Creating 3D Solid Geometry Miller: Chapter 4 Pictorial Projection Systems Bertoline: Chapter 7, Pages 329-352 SKETCH – ISOMETRIC PICTORIAL – Sketch isometric grid sheet 2 SKETCH – ISOMETRIC PICTORIAL – Sketch isometric grid sheet 3 Miller: Exercise 4.1 Wednesday – Sketch isometric grid sheet 1
Week 06 2/13	Laboratory Prep. Reading Theory Lecture Reference Readings Assignment 30 Assignment 31 Assignment 32 Assignment 33 Assignment 34	Revolved Features Miller: Chapter 4 Isometric Sketching Bertoline: Chapter 7, Pages 329-352 SKETCH – ISOMETRIC PICTORIAL – Sketch isometric grid sheet 5 SKETCH – ISOMETRIC PICTORIAL – SKETCH ISOMETRIC GRID SHEET 6 MILLER: EXERCISE 4.2 Miller: Exercise 3.6 Wednesday – Sketch isometric grid sheet 4
Week 07 2/20	Laboratory Prep. Reading Theory Lecture Reference Readings Assignment 35 Assignment 36 Assignment 37 Assignment 38 Assignment 39	Patterns and 3D Transformations MILLER: CHAPTER 5 Sections Standards and Conventions Bertoline: Chapter 8, Pages 377-405 Sketch – SECTIONAL VIEWS Sketch – SECTIONAL VIEWS MILLER: EXERCISE 5.1 MILLER: EXERCISE 5.2 Lecture Sketch – Wednesday – Orthographic grid sheet 6
Week 08 2/27	Laboratory Prep. Reading Theory Lecture	Lofted Surfaces MILLER: CHAPTER 6 Sections Standards and Conventions

	Reference Readings	Bertoline: Chapter 8, Pages 377-405
	Assignment 40	SKETCH – SECTIONAL VIEWS
	Assignment 41	SKETCH – SECTIONAL VIEWS
	Assignment 42	MILLER: EXERCISE 6.1
	Assignment 43	MILLER: EXERCISE 6.2
	Assignment 44	Lecture Sketch – Wednesday – Handout
Week 09 3/6	Laboratory Prep.	CAD Assemblies
	Reading	Miller: Chapter 7
	Theory Lecture	Introduction to Dimensioning
	Reference Readings	Bertoline: Chapter 9, Pages 424-471
	Assignment 45	Sketch – TBA
	Assignment 46	Deleted
	Assignment 47	MILLER: EXERCISE 7.1
		CATIA Parts
		CAD: Base Design
	Assignment 48	Lecture Sketch – Wednesday – Handout
	Assignment 49	
Week 10 3/13	**Spring Break**	
Week 11 3/20	Laboratory Prep.	Appendix M. **Review Miller readings**
	Reading	
	Theory Lecture	
	Reference Readings	No laboratories this week because of the sketch examination. Sketch Examination – Monday, March, 20, 2006 – 7:00 p.m. to 9:00 p.m.
	Assignment 50	**SMITH 108 – Laboratory Divisions – 01 – 05** LILLY 1105 – Laboratory Divisions – 06 – 14 Lecture Sketch – Wednesday **NOTE: Last day to cancel a course assignment may be cancelled (with passing or failing grade)**
Week 12 3/27	Laboratory Prep.	CAD Drawings
	Reading	MILLER: CHAPTER 8
	Theory Lecture	
	Reference Readings	MILLER: EXERCISE 8.1
	Assignment 51	Lecture Sketch – Wednesday
	Assignment 52	GASKET
	CATIA Files	ANSI B
Week 13 4/3	Laboratory Prep.	Model Construction with Design Intent
	Reading	
	Theory Lecture	Working Drawings
	Reference	

	Readings	MILLER: EXERCISE 8.2
	Assignment 53	Model the Lecture Handout
	Assignment 54	Produce a Dimensioned Drawing of the Lecture Handout – Use
	Assignment 55	ANSI B
		Required Views: Front, Top, Isometric
	Assignment 56	Lecture Sketch – Wednesday
	CATIA Files	COLLAR JIG
		ANSI B
Week 14	Laboratory Prep.	Exploded Assemblies
4/10	Reading	
	Theory Lecture	WORKING DRAWINGS
	Reference	Bertoline: Chapter 10, Pages 481-497
	Readings	Create an exploded assembly of your Exercise 47 CATIA
	Assignment 57	product include the bill of materials (BOM) and balloons as demonstrated in the laboratory preparation on Monday. Change the name of Part nine to nut and update the drawing to see the changes reflected in the BOM
	Assignment 58	Lecture Sketch – Wednesday
Week 15	Laboratory Prep.	
4/17	Reading	
	Laboratory	
	Theory	
	Reference	
	Readings	
	Assignment 59	
Week 16	Laboratory Prep.	Digital Mock Up (DMU) Navigator and Space Analysis
4/24	Reading	Miller: Chapter 9
	Theory Lecture	Product Lifecycle Management (PLM)
	Reference	Product Lifecycle Management (PLM)
	Readings	PURDUE UNIVERSITY PLM WEBSITE

		DIGITAL MOCK UP (DMU) NAVIGATOR AND SPACE
	Assignment 60	ANALYSIS LABORATORY
	Assignment 61	Lecture Sketch – Wednesday – Sketch combination grid sheet
	Assignment 62	12
		COURSE EVALUATION
Week 17 5/1	Finals Week	No Final Examination

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VITA

James L. Mohler

Academic Appointments

2002-05	Purdue University, Information Technology at Purdue University, Senior Research Scientist and acting Director of Informatics.
1996-	Purdue University, Department of Computer Graphics, Associate Professor, tenured and promoted in 2000.

Professional Activities

1996-	Association of Computing Machinery Special Interest Group on Graphics and Interactive Techniques (ACM SIGGRAPH) *SIGGRAPH 2005 Conference Chair* *Educators Program Chair for SIGGRAPH 2002* *Member, Education Committee*

Awards and Honors

2002	Purdue University Outstanding Undergraduate Teaching Award in memory of Charles B. Murphy.
2001	University Faculty Scholar, School of Technology.
2000	Teaching for Tomorrow Award, university-level teaching award.
1998	Outstanding Professor in Computer Graphics Award.
1997	James D. Dwyer Outstanding Undergraduate Teaching Award, School of Technology, Purdue University.
1997	School of Technology Outstanding Untenured Faculty Member.

Selected Relevant Publications

Journal Articles

(1) Mohler, J. L. (2001). Well-formedness and educational resources. *The WebNet Journal*, *3*(4), 19-23.
(2) Mohler, J. L. (2001). Visual communication en masse: An update on the Purdue University Virtual Visit. *Journal of Computers in Higher Education*, *12*(2), 70-90.

James has 10 other refereed journal articles

Proceedings (with presentation)

(1) Mohler, J. L., Glotzbach, R. J., & Kothary, N. (2003). A quantitative approach to web usability and interface design. *The Proceedings of the Vienna International Conference on eLearning, eMedicine, eSupport*. Vienna, Austria: Osterreichische Computer Gesellschaft.
(2) Mohler, J. L., Kothary, N., & Glotzbach, R. J. (2003). An investigation of best practices for interactive content controls. [CD-ROM] *SIGGRAPH 2003 Conference Abstracts and Applications*. New York: ACM SIGGRAPH.
(3) Mohler, J. L. (2001). Using interactive multimedia technologies to improve student understanding of spatially-dependent engineering concepts. *The Proceedings of the International Graphicon 2001 conference on Computer Geometry and Graphics*, Nyzhny Novgorod, Russia.

James has 25 other proceedings

*Texts and Workbooks (*denotes primary author)*

(1) Mohler, J. L., & *Bowen, K. D. (2004). *Exploring Dreamweaver MX 2004*. Albany, NY: Delmar. ISBN# 1401843859, 349 pages.
(2) Mohler, J. L. (2004). *Exploring Flash MX 2004*. Albany, NY: Delmar. ISBN# 1401843913, 316 pages.
(3) Mohler, J. L. (2004). *Flash MX 2004.* Albany, NY: Delmar, ISBN# 1401835309, 572 pages.

James has authored, co-authored or contributed to 17 other texts

Practitioner Journals

(1) Mohler, J. (2000). Web training in a flash [On-line]. *Learning Circuits* Available: http://www.learningcircuits.com/]. American Society for Training and Development.

(2) Mohler, J. L. (1997, October) Web flash: Vector is the way to go! *Web Publisher*, Informant Communications Group: California.

James has contributed to 8 other practitioner journals