INVESTIGATING THE INFLUENCE OF *QUICK DRAW* ON PRE-SERVICE ELEMENTARY TEACHERS BELIEFS, IN CONCORDANCE WITH SPATIAL AND GEOMETRIC THINKING: A MIXED METHODS STUDY

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CHAPTER I

INTRODUCTION

Spatial thinking is powerful, pervasive and is entrenched in everyday life. Spatial thinking envelops the interactions of people and objects in the three-dimensional world with respect to direction, distance, location, pattern and shape. Spatial thinking plays an integral part in scientific discoveries and progress (National Research Council, 2006) and is an essential skill for success in the STEM fields of science, technology, engineering, and mathematics. Adeptness in spatial ability can open doors to a multitude of career choices; Sorby (2009) noted that there are at least 84 careers that require spatial thinking skills. Spatial thinking is a combination of spatial sense and spatial ability and is an asset for those individuals who are interested in disciplines such as science, engineering, geography, architecture and mathematics. With respect to mathematics, the research has shown a high correlation between spatial ability and general mathematics ability (Fennema & Sherman, 1978; Anderson, 2000), spatial ability and problem solving (Battista, Wheatley, and Talsma, 1989; Woods, 1996), and spatial ability and mathematics achievement (Clements & Battista, 1992). The magnitude of the importance of spatial thinking in the context of mathematics is reinforced in every aspect of the National Council of Teachers of Mathematics

(NCTM, 2000) geometry standards for instructional programs in pre-kindergarten through twelfth grade. These geometry standards highlight four outcomes and state that students should be able to “analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships; specify locations and describe spatial relationships using coordinate geometry and other representational systems; apply transformations and use symmetry to analyze mathematical situations; use visualization, spatial reasoning, and geometric modeling to solve problems” (p. 41).

Additionally, the National Research Council (NRC, 2006) corroborates NCTM’s stance regarding spatial thinking by stating, “spatial thinking can be learned *and* it can and should be taught at all levels in the education system” (p. 3). Van de Walle (2004) and Senechal (1990) both stress that rich, hands-on experiences with shapes and activities can aid in the development of spatial thinking. Yet again this idea is supported by the National Research Council (NRC, 2006) in their position that not only can spatial thinking be developed through experiences and education, but also spatial thinking develops uniquely, depending upon each individual’s proclivity. With spatial thinking playing an integral part of geometric content knowledge, growth in spatial thinking could, in turn, enhance the overall development of an individual’s geometric thinking.

Foundation of the Problem

Since the early 1900’s, researchers have classified intellect into two categories: 1) logical thinking that is typically verbal and rational and 2) intuitive thinking that is usually nonverbal and relies on visual-spatial adeptness (Cooper, 2000). In 1938, Thurstone was the first to use the term spatial imagery, recognizing that an object can be viewed from different angles and a person can imagine himself or herself looking at the image from different perspectives (Cooper, 2000). Thurstone recognized that this ability was one from a set of abilities that was needed to be successful in the area of mathematics (Bishop, 1980). Spatial intelligence was defined by Gardner (1983) as one of the eight intelligences and is described as being the ability to recreate a visual experience with regard to shape, measurement, navigation and image.

Research has shown spatial thinking plays a role in the development of students' concepts with regard to their geometric thinking (Clements & Battista, 1992). More precisely there seems to be a relationship between spatial thinking and the five van Hiele levels that are associated with the development of geometric thinking. The first three van Hiele levels are very dependent on visual processing, although, as the van Hiele levels of geometric understanding increase, there becomes a decrease in the emphasis on visual processing skills with an increased emphasis on verbal/propositional knowledge (Clements & Battista, 1992). For students to have the potential to be successful in high school geometry they would first, essentially, need to have the necessary experiences in elementary and middle school for conquering the first three Van Hiele levels.

Problem Statement

Despite the pervasiveness of spatial thinking, its value continues to be unrecognized in the educational system (National Research Council, 2006). This dearth of opportunities to develop spatial thinking in the educational system could be a compilation of multiple factors such as teachers' lack of understanding or knowledge concerning spatial thinking, their underestimation of the value of spatial thinking, their own lack of spatial ability, or their lack of confidence in teaching to enhance spatial ability. Research has shown that teachers who are more confident in their own spatial abilities are more likely to incorporate spatial thinking into learning situations in their own classrooms (Battista, 1990). Lord and Holland (1997) discovered that pre-service secondary teachers who were specializing in disciplines that were more spatially driven, such as mathematics and science, had significantly higher spatial ability when compared to those pre-service secondary teachers in other disciplines.

Battista (1999) delineates the connection between spatial structuring and geometric reasoning and emphasizes the importance of the teaching of spatial structuring at the elementary level. Since teachers tend to teach mathematics consistently with how they were taught mathematics (Sundberg & Goodman, 2005), it would seem apparent that one place to initiate the integration of spatial thinking into the educational system would be into the pre-service elementary teacher's mathematics preparation classes. At the elementary level, children initiate having ideas about what subjects they like and dislike, and often these likes and dislikes are based upon the child's perception of what they are "good at”. At this point in time many children begin to lose interest in mathematics and science. For the integration of spatial thinking to become an area of relevant content at the elementary school level, pre-service elementary teachers would need to have an understanding of spatial thinking along with spatial thinking experiences they deem valuable. These experiences should help to develop the pre-service elementary teacher’s spatial thinking skills while simultaneously building confidence in their spatial thinking ability.

Both Chang (1992), in research with pre-service teachers, and Kotze (2007), in research with in-service mathematics teachers, found that with regard to spatial thinking these teachers tend to have a hard time interpreting characteristics and relationships involving two-dimensional and three-dimensional objects. The consensus of both researchers is that teachers need to develop spatial sense in the field of geometry. Rollick (2007) determined that pre-service teachers would benefit from the opportunity to solve, reflect upon, and discuss spatial-related activities as a part of their undergraduate curriculum, so in turn, they would have these experiences to take into their own classrooms.

A majority of the research literature links the concepts of spatial thinking with the study of geometry. Battista (2007) states that there is a need for more research in the area of geometric thinking, specifically that which could improve students’ ability to hierarchically classify quadrilaterals. Furthermore, Mayberry (1983) found pre-service teachers to be deficient in their ability to classify quadrilaterals.

A multitude of studies propose that spatial thinking can be enhanced through instruction (Bishop, 1980; Ben-Chaim, Lappan, & Houang, 1988; Battista, Wheatley, & Talsma, 1982), although presently there is a lack of research available that indicates specific activities that are time efficient and can be integrated on a daily basis into mathematics course content without having to restructure an entire curriculum. The goals of these activities would be to influence pre-service elementary teachers' spatial thinking abilities, their spatial confidence, and, more precisely, increase their exposure to interpretations of two-dimensional and three-dimensional objects which in turn also have the propensity to enhance their overall development regarding geometric thinking. As Young (1978) so aptly states, "The teacher is the key in the learning process for the classroom experiences developed by them ultimately will influence the cognitive potentials of their students in their adult life" (p. 17).

Purpose of the Study

This mixed methods research study explored the influential nature of an activity called *Quick Draw* with respect to pre-service elementary, early childhood, and special education teachers' beliefs regarding spatial thinking, their spatial ability, and their geometric thinking. *Quick Draw* activities were developed by Grayson Wheatley (2007) and consist of a complicated geometric figure being shown to the pre-service teacher for approximately three seconds; the figure is then removed from their sight and they are asked to draw the figure from memory using spatial structuring skills. Then, through questions such as "What did you see?", "How did you see this?", "What did you see first?", and "What did you draw first?" the pre-service elementary teachers will share their responses through class discussion. These *Quick Draw* activities were integrated into the Structures of Mathematics course content on a weekly basis, with eighteen *Quick Draws* completed over the period of 11 weeks. The research questions, which guide this study, were:

- Does the integration of *Quick Draw* activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for pre-service elementary teachers?
- How does the integration of *Quick Draw* activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?
- How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?

There is presently a paucity of studies in which researchers have examined techniques to augment aspects of spatial and geometric thinking of pre-service elementary teachers. To adequately answer the aforementioned research questions the design of this study was an Embedded Quasi-Experimental Mixed Methods design, which had both quantitative and qualitative components. The results of this mixed methods research study will contribute to the body of literature concerned with the preparation of pre-service elementary teachers in respect to the development of their spatial thinking beliefs, spatial thinking abilities, and geometric thinking.

Assumptions and Limitations

One assumption is that although the researcher is also the instructor of the course from which the participants were selected, this will not affect the participants' responses on the data collected. One limitation of this research is that the participants of this study are pre-service elementary, early childhood, and special education teachers, predominately white and female, enrolled in the researcher's Structures of Mathematics class. Thus being a sample of convenience, the results may not be generalizable to the general population of pre-service elementary education teachers. Secondly, the researcher of this study has been teaching the Structures of Mathematics course along with the Foundations of Geometry and Measurement course, both mathematics content courses for pre-service elementary, early childhood, and special education teachers, for approximately eight years and there is the possibility that she had some preconceived notions regarding spatial thinking, geometric thinking, and student's views regarding spatial thinking. Thirdly, the data collected through interviews is time intensive and therefore only a subset of the pre-service teacher participants were interviewed which would tend to make the results less generalizable (Johnson & Onwuegbuzie, 2004). Lastly, in qualitative interview research, the researcher is the instrument; therefore, all interpretations of the interviews are the product of the researcher's lens, albeit grounded in the data.

Definition of Terms

Foundations of Geometry: One of four mathematics content courses required of elementary, early childhood and special education majors. This course is designed to introduce students to basic concepts of geometry and measurement.

Geometric Thinking: “the ability to think and reason in geometric contexts” (Van De Walle, 2004, p. 408); specifically as seen through the van Hiele levels of geometric development joined with the ability to understand and communicate geometric terminology.

Mental Rotation: the skill associated with being able to rotate two and three-dimensional figures.

Pre-service elementary teacher: refers to students whose major course of study has been declared as elementary, early childhood, or special education.

Spatial Ability: a combination of spatial orientation and spatial visualization.

Spatial Development: stages of development of spatial thinking (Ness & Farenga, 2007).

Spatial Orientation: relationships between positions in space (Ness & Farenga, 2007); mapping and navigation skills (Clements, 1999).

Spatial Perception: spatial relationships in the environment with respect to the orientation of oneself in that environment.

Spatial Relations: a comparison of attributes such as distance, location and dimension between two objects (Ness & Farenga, 2007).

Spatial Representation: how a person mentally organizes, constructs or describes an image in the image's given place (Ness & Farenga, 2007).

Spatial Sense: intuition about shapes and the relationships among shapes; the ability to mentally visualize objects and spatial relationships (Van de Walle, 2004).

Spatial Structuring: the mental operation of constructing the form of an object through organizing the objects components (Battista, 1999).

Spatial Thinking: a combination of spatial sense and spatial abilities.

Spatial Visualization: to mentally manipulate a visual image; tasks are typically multi-step processes (Linn & Petersen, 1985).

Structures of Mathematics: One of four mathematics content courses required of elementary, early childhood and special education majors. This course is an introduction to the basic concepts of arithmetic and elementary mathematics. Course content includes problem solving, sets, whole numbers, systems of numeration, number theory, fractions, ratios, decimals, and percents.

Organization of the Study

The contents of each of the five chapters describing this mixed methods study are as follows: Chapter I consists of the introduction, foundation of the problem, the problem statement, purpose of the study, assumptions, limitations and definitions of terms used within the study. Chapter II is a review of literature as it pertains to the study. The methodology is presented in Chapter III, including the research design, participant information, instruments, data collection procedures, and procedures for analysis of the data. Chapter IV contains the results, while Chapter V discusses the findings and conclusions of the analyses along with the implications of the study and suggestions for possible future directions of research.

CHAPTER II

REVIEW OF THE LITERATURE

The goal of this chapter is to review the research literature that is pertinent to the study of pre-service elementary teachers' spatial ability, their geometric thinking, and their beliefs regarding spatial thinking. The research questions, which guide this study, are:

- Does the integration of *Quick Draw* activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for elementary, early childhood, and special education pre-service teachers?
- How does the integration of *Quick Draw* activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?
- How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?

The major areas of research relevant to the present study include:

1. Spatial thinking: A historical background followed by connections mathematics, teaching, teachers, gender, and research regarding the instrument used in this study to measure spatial thinking.
2. Geometric thinking: A historical background followed by connections to teaching, teachers, and research regarding the instruments used in this study to measure geometric thinking.
3. Spatial and geometric thinking: Connections between the van Hiele levels and spatial visualization, Vygotsky's zone of proximal development, teaching to enhance spatial and geometric thinking, and the inter-relatedness of spatial and geometric thinking.
4. Attitudes regarding spatial thinking.

Spatial Thinking

A Historical Perspective of Spatial Thinking

The history of spatial thinking is rich in research and theory. Albeit not practical to include the complete history, an overview is appropriate to provide an introduction to the main focus of the research study. Since the early 1900's, researchers have classified intellect into two categories, the first being verbal/rational/logical and the second being visual-spatial/ nonverbal/intuitive (Cooper, 2000). In 1925, McFarlane pioneered research in the visual-spatial area when she set out to determine a subject's "practical ability," which she saw being distinctly different from verbal ability. Ten years later, Koussy (1935) compiled 28 tests, which at the time were being used to determine what was then called spatial intelligence. In 1938, Thurstone was the first to use the term “spatial imagery”, recognizing that an object can be viewed from different angles and a person can imagine himself or herself looking at the image from different perspectives (Cooper, 2000). Thurstone recognized that this ability was one from a set of abilities that was needed to be successful in the area of mathematics (Bishop, 1980). Additionally, in 1983 spatial intelligence was defined by Gardner as one of the eight human intelligences and is described as being the ability of recreating a visual experience with regard to shape, measurement, navigation, and image. He categorized the other intelligences as linguistic, logical-mathematical, bodily-kinesthetic, musical, interpersonal, intrapersonal, and naturalistic.

There are four prevalent perspectives regarding spatial thinking (Ness & Farenga, 2007). The Vygotskyan perspective emphasizes spatial thinking ability to be intrinsically connected to one’s own culture. The nativist perspective links spatial thinking ability as a by-product of genetics. The Piagetian developmental perspective is based on research conducted by Piaget. Lastly, the interactionist approach suggests that spatial thinking ability is a combination of all three of the aforementioned perspectives.

Although there are many researchers who have contributed to the body of knowledge pertaining to spatial thinking, the foundation for most of the theory associated with spatial thinking is derived through the work of Piaget. In 1954, Piaget (1967) posited that children's development of space begins at infancy. Piaget and Inhelder are responsible for much of the current thought with respect to children's construction of conceptual space. Two major themes from their work emerged regarding a child's conception of space (Piaget & Inhelder, 1967). First, a child's conception of space is constructed progressively through their previous manipulations and experiences with space. Secondly, a child's conception of geometric ideas is attained in a specific, logical order- first by shape and then by properties. The first theme, verified through replications in other studies (Clements & Battista, 1992), and recently by Ness and Farenga (2007) who researched block play with respect to children's geometric and spatial thinking. Conversely, the second theme has not been able to be consistently corroborated. The ambiguity of the results, in replicated studies of the second theme, has lead researchers to believe that it is more likely that children's geometric ideas evolve over time. These geometric ideas become increasingly interwoven in the contexts of shape and properties as they are manufactured over time (Clements & Battista, 1992).

In 1974, Milner determined that the right hemisphere of the brain controls spatial abilities by studying individuals with brain injuries. This thought parallels Krutetskii's (1976) determination that there were two modes of thinking, one being verbal-logical (left brain) and the other visual-pictorial (right brain). Krutetskii (1976) then classified students as being analytic if they showed strong verbal-logic tendencies, geometric if they showed strong visual-pictorial tendencies and harmonic if they showed no particular preference for either verbal-logic or visual-pictorial. More recently, in 1994, Posner and Raichle found that individuals who suffered from damage to the right side of the brain saw only the parts of an object but were unable to put the parts together to form a whole. Those individuals who had suffered from damage to the left side of the brain saw the object as a whole and were unable to identify the parts of the object. This research paralleled Kosslyn's (1994) conclusion that to form an image, perceptual wholes are built up from representations of parts and the interrelatedness of parts. This holistic-to-parts processing is not necessarily intuitive but can be developed with experiences. Kosslyn's holistic-to-parts ideology mimics the gestaltist view of spatial ability as opposed to the analytic view of spatial ability. The gestalt view is based on the ability to perceive, retain and transform a figure as an organized whole (Bishop, 1980) while the analytic view is based on the premise that the whole is broken into parts at which time the parts can be mapped in a one-to-one correspondence (Bodner & Guay, 1997). Most recently, in 1997, Smith and Jonides used positron emission tomography (PET) scans in determining that when individuals were solving spatial tasks, all four active areas of the brain, were located on the right side. When individuals were involved in verbal tasks, six of the seven active areas were located on the left side of the brain with the seventh area being located in the middle of the brain.

Spatial Thinking and Mathematics

Spatial thinking is found in many aspects of life, everything from understanding directions and maps to catching a ball to re-arranging furniture in a room. In this research study, spatial thinking along with geometric thinking were the two factors that were being investigated. In a broader sense, first a background of the relationship between spatial thinking and mathematics needs to be examined. In 1985, Fennema and Tartre determined through their research that there is a high correlation between spatial visualization and mathematics ability. They also found that students with high spatial ability and low verbal ability were better at translating problems into pictures than those students who had low spatial ability and high verbal ability. Although, no significant differences in the problem-solving processes between these students were found. Contrary to the previous findings, Lean and Clements (1981) determined that students who use a verbal-logical means to process mathematical information perform significantly better than those who only use a visual means to process mathematical information. Moreover, Cirino, Morris, and Morris (2007) concluded that visuospatial skills were not predictive of mathematical computational skills in college students who had been reported to be experiencing academic difficulty.

According to Clements and Battista (1992), high correlations have been found to exist between spatial ability and mathematics achievement at all grade levels. There is also much research that contradicts these claims, for example Battista, Wheatley, and Talsma (1982, 1989), noted there to be no significant correlation between spatial ability and mathematics achievement in both of their studies involving pre-service teachers.

One interesting aspect of research involving spatial thinking regards an overlooked group of individuals: students with high spatial ability who seem to lack skills in other areas. As a child, Edison was thought to be dull (Mann, 2005), and Einstein, who was known for his struggles with mathematics, noted that his thoughts were not words but images. Einstein related that his ideas of relativity were conceived by imagining himself in a space ship traveling at the speed of light (Cooper, 2000). Mann (2005) states that it is not uncommon for students who have high spatial ability to be labeled as having a learning disability. Yet she continues to say if these children are nurtured, they will have opportunities to be successful, particularly in the STEM-related fields of science, technology, engineering and mathematics. Since these fields rely on a high degree of spatial ability.

In the same context, Brown and Wheatley (1989) compared two groups of fifth-grade students; one group with low spatial ability who had scored average to above average on a standardized mathematics test, and the other group with high in spatial ability, but had scored average to below average on the standardized mathematics test. Clinical interviews revealed that the first group struggled in the area of problem-solving while the second group excelled in problem-solving. More recently, Hannafin, Truxaw, Vermillion, and Liu (2008) revealed that sixth grade students, classified as high spatial ability, scored significantly better on a geometry unit post-test when compared to those students with low spatial ability. These results were independent of the treatment used to teach the sixth grade students a unit in geometry. Finally, Smith and Olkun (2005) determined that for a group of nine-year olds, interactively manipulating shapes on computer program verses passively watching the computer rotating the shapes led to an improvement in mental rotation skills. Interestingly enough, these researchers did not have the same results when applying their study to college undergraduates. Apart from mathematics, another discipline that is spatially driven is that of geography. Schoenfeldt (1999) discovered there to be no connection between spatial ability in pre-service teachers and the amount of completed coursework in geography or in their area of concentrated study.

Overall, the variety of outcomes seen in the research would seem to infer that the relationship between spatial thinking and mathematics is complex and multi-dimensional as opposed to one-dimensional. The variables are the type of spatial thinking measurement administered and the classification of the mathematics being evaluated.

Teaching and Spatial Thinking

The participants in this research study were pre-service elementary, early childhood, and special education teachers who will soon be in-service teachers. An area of interest is to examine what relationships exist between spatial thinking and teaching. Lord and Holland (1997) discovered that pre-service secondary teachers who were specializing in disciplines that were more spatially driven, such as mathematics and science, had significantly higher spatial ability when compared to those pre-service secondary teachers in other disciplines. Furthermore, research has shown that teachers who are more confident in their own spatial abilities are more likely to incorporate spatial thinking strategies into learning situations in their own classrooms (Presmeg, 1986; Battista, 1990). Explicitly, Presmeg (1986) points out, “Teachers in the non-visual group dispensed with visual presentations whenever possible, teachers in the middle group used visual presentations but devalued them, while teachers in the visual group used and encouraged visual methods” (p. 308).

A study involving pre-service elementary teachers regarding mathematics teaching effectiveness found there to be no significant correlation between spatial ability and mathematics teaching effectiveness. Although there was a significant positive correlation found between spatial ability and mathematics content knowledge (Hadfield, Oakley, Littleton, Steiner, Robert, & Woods, 1998). Although, this would seem to imply one does not necessarily have to have high spatial reasoning to be an effective teacher of mathematics; this study says nothing to attest for the instruction of spatial thinking in the classroom.

Pre-service Elementary Teachers and Spatial Thinking

Most of the studies involving pre-service elementary teachers and spatial thinking involve comparing spatial thinking as measured through a variety of spatial thinking tests to other constructs. This is seen within the study in which Battista, Wheatley, and Talsma (1982) investigated the relationships between spatial visualization ability, cognitive development, and achievement in pre-service elementary teachers. They determined that there was no significant difference found with respect to the interaction between the three factors of spatial visualization ability, cognitive development, and achievement. The results of the pre-spatial visualization ability test and the post-spatial visualization ability test showed that there was a statistically significant improvement in this area. The researchers attributed this phenomena to the effect of the semester long geometry course that had been designed with numerous class activities in which spatial components were integrated. In another study, Battista, Wheatley and Talsma (1989) found that spatial visualization was related to problem-solving performance, but not to achievement among a group of pre-service elementary teachers. These pre-service teachers were introduced to two problem-solving strategies, drawing and visualization; although they were more successful in problem solving when using the drawing strategy, most pre-service teachers favored the visualization strategy. Similarly, Woods (1996) found that there was a significant positive relationship between pre-service elementary teachers' mathematical word problem-solving performance and their spatial ability.

Both Chang (1992), with respect to pre-service teachers, and Kotze (2007), with respect to in-service mathematics teachers, found that these teachers tend to have a hard time interpreting characteristics and relationships involving two-dimensional drawings of three-dimensional objects. The consensus of both researchers was that there is a need to integrate the development of spatial thinking in the content of courses in geometry.

Rollick (2007) devised, through her research with pre-service elementary teachers, a spatial reasoning model. This model consisted of a combination of three categories. The first category was spatial experiences such as those obtained in childhood, at school, and in play. The second category included spatial strategies such as finding patterns and structuring, and the last category incorporated drawing and verbalizing representations. Rollick (2007) concluded from her investigation that pre-service teachers would benefit from the opportunity to solve, reflect upon, and discuss spatial-related activities as a part of their undergraduate curriculum.

Recently, the focus of the research conducted by Smith, Gerretson, Olkun, Yuan, Dogbey, and Erdem (2009) dealt with the feasibility of spatial training with respect to pre-service elementary teachers by means of a computer based intervention. The researchers determined that although the students' spatial visualization (which they defined as the process of being able to solve multiple step problems with respect to configuring shapes) did improve significantly, their mental rotation ability (the ability to mentally rotate shapes into new orientations) did not improve significantly. The researchers attributed these results to the fact that the computer intervention that was used for spatial training employed a combination of multiple, discrete, stepwise rotations of an object, hence fitting their definition of spatial visualization, as opposed to continuous, non-stop, full rotations of an object, hence mental rotation. Thus, they concluded that the intervention was more like the spatial visualization test that had been administered and less like the mental rotation test that had been administered. This reinforces the idea that spatial thinking can be learned although it is developed per unique contexts and is not necessarily transferable (NRC, 2006).

In another study, Spencer (2008) discovered that introducing concrete tangram puzzles or digital tangram puzzles or both concrete and digital tangram puzzles into course content for pre-service elementary teachers significantly improved their spatial thinking ability. Furthermore, Spencer (2008) found these pre-service elementary teachers demonstrated a significant increase with respect to their attitude toward geometry.

Gender and Spatial Thinking

Typically pre-service elementary, early childhood, and special education teachers are predominately female. Therefore, the research relating to spatial thinking with regard to gender is inherently important. There is a plethora of research that supports the existence of male dominated gender differences in spatial thinking (Shepard & Metzler, 1971; Battista, 1990; Clements & Battista, 1992; Voyer, 1998). Although the reasons associated with this phenomena are not concrete, speculation by researchers range from differences concerning the processing of spatial tasks, to brain organization, to the culmination of an individual's spatial experiences (as cited in Bodner & Guay, 1997).

With respect to differences concerning the processing of spatial tasks, Cochran and Wheatley (1988) determined undergraduate males outperformed undergraduate females only on the harder of two spatial ability tests. On the DAT (Differential Aptitude Test: Space Relations subtest), there were no significant differences in gender, although on the ROT (Purdue Spatial Visualization Test: Visualization of Rotations subtest), there were significant differences with respect to gender. No significant differences were found in strategy use between genders. The researchers suggest that these conclusions taken together imply that although there is no difference in strategy for easier spatial tasks, having a wider variety of strategies may be an important factor in solving more complicated spatial ability tasks. In 1985, Fennema and Tartre conducted a longitudinal study following students from the 6th through the 8th grade to determine the use of spatial visualization in problem solving with respect to gender. Overall, they found that students who had low spatial ability, as determined by the DAT, solved no less problem-solving problems than did those students with high spatial ability. However, they determined that there were significant gender differences with respect to the student's ability to use picture representations during fraction problem-solving.

The results between gender and spatial ability have lead researchers to investigate the possibility of the differences resulting from biological factors between the sexes. Studies, such as those dealing with left-or right-handedness (Gilleta, 2007), brain activity (Jausovec & Jausovec, 2007), and the parietal lobe of the brain along with gray and white matter volume (Koscik, O'Leary, Moser, Andreasen, & Nopoulos, 2009) are just a few. In the latter, the researchers found that structural differences in the parietal lobe of the brain do corresponded significantly to spatial ability as measured by the Mental Rotations test (MROT). Men were found to have a larger surface area of their parietal lobe, which was determined to be an advantage in spatial ability level, while women were found to have more gray matter volume in their parietal lobe, which was determined to be a disadvantage with respect to spatial ability level.

The Fennema and Sherman study in 1977 was decidedly a key study with respect to gender. The researchers determined that only two of the four high schools involved in the study showed a significant difference in gender and spatial ability as measured by the DAT. To ensure like backgrounds, these participants in 9^{th} through 12^{th} grade had all been enrolled in mathematics classes. The researchers attributed these contradictory findings to two factors, first that there appears to be a socio-economic factor involved. A socio-economic factor along with culture would tend to affect the culmination of a child's spatial experiences. Our culture tends to encourage boys to play with blocks and girls to play with dolls. The second factor conjectured by Fennema and Sherman (1977) was that gender attitudes and beliefs also seem to play a role in spatial thinking.

Beliefs and confidence play an integral part of a person's vision regarding life in general. More specifically, not only do beliefs and confidence play a vital role in how students learn but also gender role beliefs influence spatial ability performance (Massa, Mayer, & Bohon, 2005). Moe and Pazzagalia (2006) manipulated the instructions to the MROT spatial ability test and found that if the directions informed the students that females were better at solving spatial tasks, then the females scored significantly higher on the MROT part two and the males' scores fell. If the directions indicated that males were better at solving spatial tasks, then the males scored significantly higher on the MROT part two and the females' scores fell. There were no significant differences in the scores of those students who took the MROT with no reference to gender in the directions.

Linn and Hyde (1989) have shown through a meta-analysis of research on gender and spatial ability that the gender gap with respect to spatial ability is diminishing. They suggest that these results are in part due to the fact that gender differences in spatial tasks respond to training, which is verified in a variety of studies (Ferrini-Mundy, 1987; Rafi, 2008; Sorby, 2009). However, there are some research studies that have opposite conclusions. Both Ben-Chaim, Lappan, and Houang’s (1988) research with fifth through eighth grade students and Clements, Battista, Sarama, and Swaminathan’s (1997) research with third graders initially showed significant differences in spatial ability with respect to gender. In both cases, following a spatial visualization unit, significant gains were attained for all students regardless of gender, although this training did not necessarily reduce the gender differences in spatial ability.

Overall, the research seems to imply that spatial development training may tend to benefit females more than males. Fennema and Tartre (1985) posited that low spatial ability seemed to hinder girls’ mathematics achievement more than boys. This coincides with the conclusion that Friedman (1995) reached after conducting a meta-analysis of correlations between spatial ability and mathematical skills. “The relationship between computational skills and spatial skills is, apparently, slightly stronger for females than males. This result is consistent with Tartre’s (1990) remark that females with low spatial skills have difficulties with many kinds of mathematical tasks, whereas males with low spatial skills appear to be able to compensate using other skills” (Friedman, 1995, p. 40).

Measuring Spatial Thinking

In general, researchers suggest three categories of spatial ability measures: measures of spatial perception, measures of mental rotation, and measures of spatial visualization (Olkun, 2003; Clements & Battista, 1992; Linn & Petersen, 1985). Consequently, they list a variety of tests that can be used to measure each of these categories. The Purdue Spatial Visualization Test (PSVT) is comprised of three parts: Developments, Rotations, and Views. Each part of the test corresponds to the three components of spatial ability as described previously. The Developments section consists of twelve questions designed to measure an individual's spatial visualization through spatial structuring, the Rotations section consists of twelve questions designed to measure an individual's mental rotation ability, and the Views section consists of twelve questions designed to measure an individual's spatial perception. Other tests commonly used to measure spatial ability such as the Group Embedded Figures Test, Mental Rotations Test, and the Differential Aptitude Test: Space Relations subtest tend to only emphasize one of the three components of spatial ability. Each of the aforementioned measures uses depictions of three-dimensional objects. The Wheatley Spatial Ability Test is a measure of mental rotation using two-dimensional objects and is geared for younger students. Since spatial thinking is found in multiple contexts, each unique, and not transferable (NRC, 2006), researchers have also developed their own spatial thinking instruments to satisfy their own specific research requirements (Ganesh, Wihelm, & Sherrod, 2009).

Geometric Thinking

A Historical Perspective of Geometric Thinking

The foundation of geometric thinking in this study is based on the van Hiele Level Theory. In the 1950's, the Dutch educators Pierre van Hiele and his wife Dieke van Hiele-Geldof developed a theory regarding the learning of geometric concepts, which was presented in a short paper titled, "The Child's Thought and Geometry" (Musser, Burger, & Peterson, 2006). The paper, translated to English, describes a theory based on the premise that geometric concepts are learned sequentially and individuals will progress through five developmental levels (Fuys, 1988). These levels are seen as either being labeled 0 through 4, or labeled 1 through 5.

Level I (Recognition): The student views shape holistically with no regard to the shapes component parts.

Level II (Analysis): The student focuses analytically on component parts of a figure and uses these to describe or characterize the figure.

Level III (Relationship): The student understands relationships and uses deduction to justify their observations. At this level the classification of geometric shapes such as quadrilaterals occurs.

Level IV (Deduction): The student understands postulates and theorems and the writing of formal proofs.

Level V (Axiomatics): This last level is highly abstract; this level does not rely on pictorial or concrete models.

Although not acknowledged by the van Hiele's (1986), the existence of a level that is below the first van Hiele level is the subject of much debate (Usiskin, 1982; Clements & Battista, 1990). This pre-operational level is defined by Clements and Battista (1990) as being *Level 0* (Pre-recognition): “Children initially perceive geometric shapes, but attend to only a subset of a shape's visual characteristic. They are unable to identify many common shapes” (p. 354).

Research has shown that the van Hiele levels are accurate with respect to describing student's development of geometric concepts from elementary school through college (Clements & Battista, 1992). There is, however, a controversy as to whether these five van Hiele levels are discrete. Researchers have found difficulty in classifying students who appear to be in a transition between two levels (Usiskin, 1982), while others speculate as to whether a perfect fit into a specific level is possible (Kotze, 2007). In 1983, Mayberry found that pre-service elementary teachers could possibly be simultaneously on more than one van Hiele level, depending upon the specific geometric content in question. In 1988, Fuys discovered that when any new geometric concept was introduced to a student, the student typically began their understanding at Level I but would quickly be able to move to the higher van Hiele levels at which they had come to understand other geometric concepts. From this, the researcher concluded that the student's “potential” van Hiele level was consistent across geometric concepts.

Teachers and Geometric Thinking

As mentioned previously, with the participants of this study being pre-service teachers, the relationship between teaching and the van Hiele levels should be considered. Henderson's (1988) research involved observations of pre-service secondary mathematics teachers who were involved in small group discussions with high school geometry students. The researcher determined that the pre-service teacher's ability to adjust their instruction with respect to the high school student's insights or confusions was influenced and limited by their own van Hiele level of understanding. Additionally, Halat (2008) concluded that, although there were no significant differences between gender and van Hiele levels of pre-service elementary teachers, there was a significant difference between van Hiele levels and gender, favoring males, of pre-service secondary mathematics teachers.

Pre-service Elementary Teachers and Geometric Thinking

Roberts (1995) established a significant positive correlation between pre-service elementary teacher's van Hiele level and whether they had taken a geometry course in high school, although there was no relationship between van Hiele level and demographic variables of these pre-service elementary teachers such as type of community, high school class size, gender, or race. Parson's (1993) research showed that the van Hiele level of a pre-service elementary teacher was influential with respect to the van Hiele level of the geometry lesson that they created. These created lessons were either at the same van Hiele level of the pre-service teacher or they were at lower van Hiele levels.

Mayberry (1983) came to three conclusions through her research with pre-service elementary teachers: first, that the van Hiele levels were sequential in nature in that a student must capture the essence through experiences of one level in order to successfully move into the next level. Secondly, that geometric content knowledge for these pre-service teachers was inadequate, and thirdly, Mayberry (1983) concluded that the geometric terminology being used in instruction cannot be on a higher van Hiele level than that level where the student is situated if there is to be understanding of the geometric concepts being addressed. This difficulty associated with understanding geometric vocabulary tends to be an underlying theme as it is seen also in Chang's (1992) research when he determined that pre-service teachers struggle with understanding and communicating the mathematical language associated with geometric thinking. Finally, Knight (2006) determined that there were pre-service elementary and secondary teachers below the third and fourth van Hiele levels, or below the levels where students are anticipated to be between the eighth through twelfth grade. Undoubtedly, this is not ideal since teachers play such a major role in student learning.

Measuring Geometric Thinking

The Van Hiele Geometry Test (VHGT) measures the geometric developmental level of an individual. This test was created for The Cognitive Development and Achievement in Secondary School Geometry (CDASSG)

Project (Usiskin, 1982) and consists of twenty-five questions, five questions for each developmental level. Permission to use this test is granted through the author, Dr. Zalman Usiskin who in turn keeps a record of all requests and research findings. To date, Dr. Usiskin has a list of fifty-seven studies in which the VHGT has been the van Hiele measure. Other measures for determining van Hiele levels have been researcher created (Kotz, 2007) or those that employ Mayberry's (1983) clinical interview protocol.

Spatial and Geometric Thinking

The Van Hiele Levels and Spatial Visualization

The fact that these ideas involving the development of spatial thinking are related to topics in geometry imply that therein lies a type of epiphytic relationship in which spatial thinking is supported through geometric thinking, although not dependent on geometric thinking. Thus, there would naturally seem to be a connection between spatial thinking and van Hiele's (1999) ideas regarding the development of geometric thinking: "…instruction intended to foster development from one (van Hiele) level to the next should include sequences of activities, beginning with an exploratory phase, gradually building concepts and related language, and culminating in summary activities that help students integrate what they have learned into what they already know" (p. 310).

Research has shown spatial thinking to play a role in the development of students' concepts with regard to their geometric thinking; more precisely, there is a relationship between spatial thinking and the five van Hiele levels of development of geometric thinking. The van Hiele Level I (recognition) is a nonverbal level and is very dependent on visual processing (van Hiele, 1999). As the van Hiele levels increase, there is a decrease in emphasis of visual processing skills with an increased emphasis on verbal/propositional knowledge (Clements & Battista, 1992). This verbal/propositional knowledge is an integral part of geometric thinking, which takes time to develop (Clements, 1998) and can be seen as being linked to geometric thinking through Vygotsky's zone of proximal development.

Vygotsky, Spatial Thinking and Geometric Thinking

Researchers have suggested that the human mind tends to categorize objects into two main categories, fuzzy or formal (Battista, 2007). Fuzzy categories have no clear definition or boundaries and consist of everyday experiences or instances; these are similar to what Vygotsky (1986) refers to as spontaneous concepts. Formal categories are explicitly, precisely defined; these concepts are what Vygotsky (1986) refers to as scientific concepts. Vygotsky's (1986) theory posits: "Scientific concepts grow downward through spontaneous concepts; spontaneous concepts grow upward through scientific concepts" (p. 194). These thoughts led to the development of Vygotsky's "zone of proximal development" or ZPD. The ZPD is the area in between unassisted performance (spontaneous concepts) and assisted performance (scientific concepts). Success in learning will take place if the teacher meets the student in this area. As

Vygotsky (1986) states: "…the development of concepts and the development of word meanings are but two forms of one and the same process…" (p. 160).

Applying Vygotsky's ZPD theory to geometric and spatial thinking leads to the conception and development of geometric shapes, their properties, attributes, and spatial structuring. As viewed through the constructivist lens, these geometric shapes and their spatial structuring are initially spontaneous concepts derived through daily interaction with the world around us. Through rich, hands-on experiences, these spatial representations can lead to formal verbal/propositional geometric concepts. In an example employing geometric vocabulary, a student might typically refer to a rhombus (scientific concept) as a diamond (spontaneous concept), although with the proper experiences these two concepts merge in the geometric zone of proximal development.

Richardson and Stein (2008) reinforce this idea between geometric shape and vocabulary, "One preservice teacher, who regularly implemented Quick Draw with an entire class of middle–grades students, noted that although the students were exposed to mathematical vocabulary on a continuing basis in the classroom, they seem to use it more readily during the *Quick Draw* activity. She compared the experience with learning a list of vocabulary words, then being asked to use those words in a sentence" (p. 106). This example illuminates the difference between memorizing vocabulary out of context (scientific concepts) verses actually having understanding of the meaning or experiencing the concept (spontaneous concepts) of the vocabulary term.

Teaching for the Purpose of Improving Spatial and/or Geometric Thinking

The notion of the importance of developing spatial thinking as viewed through the NCTM standards (2000) seems to be ubiquitous in the literature with educators reporting their integration strategies. For the most part, these strategies are highlighted as being single attempts such as high school students solving "Polya's Five Plane Problem" (Madden & Diaz, 2008) with the aid of computer graphics, or middle school students finding the volume of a rectangular prism through discovery (Chavez, Reys, & Jones, 2005) to efforts such as introducing engineering drawing to middle grade students (Olkun, 2003). In another context, Guven and Kosa's (2008) research was directed at improving pre-service mathematics teachers' spatial thinking through use of a geometry software computer program. Their results showed this intervention to be effective as indicated by the significant increase in the spatial ability test scores.

Yackel and Wheatley (1990) introduced two activities to second graders, a tangram activity and the *Quick Draw* activity, and observed that these activities were successful in not only encouraging the spatial thinking aspect of rotating images but also in helping to develop the geometric thinking aspects of recognizing and drawing shapes, and additionally promoting the use of the geometric vocabulary associated with these shapes. Bentley (1999) similarly concluded that the *Quick Draw* activity introduced to her fifth grade students expanded their geometric vocabulary. More recently, Richardson and Stein (2008) implemented the *Quick Draw* activity with pre-service teachers. These pre-service teachers then took the *Quick Draw* activity into their own middle-grades classroom under the guidance of their cooperating teachers. In all instances, the conclusions of the researchers were the same; the *Quick Draw* activity was seen to develop geometric vocabulary, and communication skills, as well as confidence in communicating geometric terminology. The spatial thinking attributes of *Quick Draw* is described succinctly by Clements (1998) when he stresses the importance of giving students the opportunity to decompose and compose shapes, a wide variety of shapes so as not to limit their experiences with specific common shapes.

Unfortunately, the emphasis on developing spatial thinking was prevalent two decades ago (Kaput, 1989; Ben-Chaim, Lappan, & Houang, 1988; Hershkowitz, 1989), and ten years later Clements (1998) reiterated the fact that spatial and geometric reasoning skills were still not being emphasized adequately by early childhood and primary educators. The importance of the integration of these spatial and geometric skills into the curriculum on a regular basis is best summed up by Clements and Del Campo (1989): “It can be concluded that teaching programs which result in children establishing not only mental images and verbal propositions in their cognitive structures, but also the memory of episodes involving active manipulation of physical objects, and group discussion, are likely to result in effective long-term learning taking place” (p. 32).

By placing more of an emphasis on spatial and geometric thinking in the elementary and middle grades, students will have the prerequisite knowledge to be more successful in their high school coursework. Courses such as high school geometry have been documented as being problem areas with students being under prepared with respect to spatial and geometric thinking (van Hiele, 1999). Success, in general, fosters positive attitudes; success in mathematics and science will create a chain reaction, keeping students' interest peaked. In turn, these students will pursue future coursework in the fields of mathematics and science and will lead to future career decisions in favor of these fields. Sherman (1983) concluded that not only was a student's confidence in learning mathematics a powerful deciding factor as to determining what mathematics classes were pursued in high school but also that, with respect to females, spatial skills were a big determinant.

Inter-relatedness of Geometric Thinking and Spatial Thinking

The research, which shows the relationship or lack of relationship between spatial thinking and geometric thinking, is meager and contradictory. Bishop (1990) found significant correlations between high school student's geometry achievement scores and spatial ability, and additionally found a significant correlation between low-level geometry achievement with the factors of spatial ability and geometric problem-solving. Apart from this study, each of the following studies were dissertation studies obtained by means of the Digital Dissertation database. Naraine (1989) found a significant correlation between van Hiele levels and spatial ability through a study with college students. In this study the van Hiele levels were measured by means of a multiple choice geometry test and spatial ability was measured using the Mental Rotations Test (Vandenberg & Kuse, 1978). Mixed results were found in Hvizdo's (1992) research, when she determined that there was a positive correlation between spatial ability and geometry test grades for high school students with respect to two out of the four total grading quarters. In this study, the Career Ability Placement Survey measured spatial ability.

In a study whose focus was a geometry software program in a high school geometry class, Smyser (1994) found that there was no significant relationship between spatial thinking and van Hiele level. In this particular study, the van Hiele level was measured with the Van Hiele Geometry Test (Usiskin, 1982) and spatial thinking was measured with the Card Rotation Test. Additionally, Fitzsimmons (1995) also found there to be no significant correlation between spatial ability and van Hiele level while studying college students enrolled in a calculus class. The tests, which were chosen to measure spatial ability and van Hiele levels, were not documented in the researchers abstract and the dissertation was not available.

Attitudes Regarding Spatial Thinking

In general, attitudes concerning mathematics are comprised of two elements: “feelings about mathematics and feelings about oneself as a learner of mathematics” (Reyes, 1980, p. 164). Comparably, it could be restated that attitudes concerning spatial thinking are comprised of two elements, feelings about spatial thinking and feelings about oneself as a learner of spatial thinking. These two aspects can be more broadly described as beliefs or firmly held opinions with respect to spatial thinking, and confidence or the feeling of selfassuredness that evolves from a person's own spatial thinking ability. Overall, beliefs and confidence play an integral part of a person's vision regarding life in general. More specifically, beliefs and confidence play a vital role in how students learn, how teachers teach, and, additionally, "preservice teachers' beliefs and attitudes also play an important role in their learning to teach" (Wagner, Lee, & Ozgun-Koca, 1999, p. 1).

Research has shown that teachers who are more confident in their own spatial abilities are more likely to incorporate spatial thinking into learning situations in their own classrooms (Battista 1990). One of the many aspects of incorporating spatial thinking into the classroom is with the use of drawing pictures or shapes to represent mathematical and geometric problems. Clements (1998) points out that drawing is a type of representation that actually demonstrates a person's understanding of an idea or concept, thus reinforcing the connection between spatial thinking and verbal, propositional knowledge.

Although there is an absence of literature associated with attitudes regarding spatial thinking, the rationale of the study of pre-service elementary teachers' attitudes regarding spatial thinking should be of obvious importance. Teachers' attitudes toward spatial thinking, be it a positive attitude or a negative attitude, as any attitude in general, will not only be reflected onto their students but can influence their students as well.

Summary

The research has shown spatial thinking to be a multifaceted, complex phenomenon. Although the “why” and “how” regarding spatial thinking may not be fully understood, the various facets of spatial thinking are found to be essential components not only in the area of geometric thinking but also in the fields of mathematics, science, geography, engineering, technology, air traffic control, interior design, and architecture. The National Council of Teachers of Mathematics (2000) states, “Instructional programs from pre-kindergarten through grade 12 should enable all students to use visualization, spatial reasoning, and geometric modeling to solve problems” (p. 41). Exploring pre-service elementary teachers’ spatial thinking, their geometric thinking, and their beliefs regarding spatial thinking could provide insight into future educational policy, especially policy involving teacher education programs for pre-service elementary, early childhood, and special education teachers.

CHAPTER III

METHODOLOGY

The purpose of this mixed methods study was to address spatial thinking, geometric thinking, and beliefs regarding spatial thinking of elementary pre-service teachers through an activity called *Quick Draw*. The researcher, through a pragmatic worldview, used an Embedded Quasi-Experimental Mixed Methods design. This type of design integrated the collection of different, although complimentary quantitative and qualitative data to enhance the study of spatial thinking, geometric thinking, and beliefs regarding spatial thinking of pre-service elementary teachers through the *Quick Draw* activity (Creswell, 2007).

In this design, the qualitative data set provided a supportive, secondary role with the quantitative data set providing the primary role (Creswell, 2007). The quantitative instruments used in this study were the PSVT- Purdue Spatial Visualization Test (Bodner & Guay, 1997) as a measure of spatial thinking, the VHGT- Van Hiele Geometry Test (Usiskin, 1982) and the GV- Geometric Vocabulary test as measures of geometric thinking, and the STAS- Spatial Thinking Attitude Survey (Hanlon, 2009) as a measure of beliefs regarding spatial thinking. The collection of the qualitative data involved written responses to the *Quick Draw* activity, journal prompts, semi-structured interviews, written responses from the Geometric Vocabulary test (GV), and field notes.

Overall, the quantitative and qualitative results obtained through these instruments were analyzed to determine how the implementation of the *Quick Draw* activity influenced the spatial thinking, geometric thinking, and beliefs regarding spatial thinking of pre-service elementary teachers. Additionally, analyses of the qualitative data explored the phenomena of how the pre-service elementary teachers view their understanding of spatial thinking, geometric thinking, and attitudes regarding spatial thinking. Collecting both the quantitative and the qualitative data informed the researcher through the interpretation of the results from two different perspectives, and in fact, enhanced the findings regarding spatial and geometric thinking. The research questions guiding this study were:

- Does the integration of *Quick Draw* activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for pre-service elementary teachers?
- How does the integration of *Quick Draw* activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?
- How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?

The Mixing of Quantitative and Qualitative Methods

There is some controversy with respect to the mixing of quantitative and qualitative research designs. Both quantitative and qualitative purists can be found who believe that these approaches should not be mixed due to the fact that the theoretical perspectives that inform each of these designs are in opposition of one another. However, Creswell and Plano Clark (2007) state, "The focus is on the consequences of research, on the primary importance of the question asked rather than the methods, and multiple methods of data collection inform the problems under study. Thus it is pluralistic and oriented toward 'what works' and practice" (p. 23). Shutz, Chambless, and DeCuir (2004) also ascertain this practicality by emphasizing that the method consists merely of the tools used that will best answer the research questions and should not be judged by it's origin. In this sense, then, the pragmatist approach can be seen as a worldview for the mixed methods design.

Additionally, Morse (1991) justifies this stance by saying that a quantitative precedence is driven by a post-positivistic worldview, a qualitative precedence is driven by a naturalistic worldview, and the combination of a qualitative and a quantitative precedence, either equally or not depending on the research questions, is driven by the pragmatic worldview. By using the pragmatist approach, research now becomes a problem-solving activity. Shutz, Chambless, and DeCuir (2004) state, "When we conceptualize research as a problem-solving activity, we also suggest that any method, within moral and ethical constraints, can be used" (p. 274), consequently rationalizing the integration of what some infer as being the two opposing perspectives of post-positivism and interpretivism.

Researchers describe several types of mixed methods designs including Triangulation Design, Explanatory Design, Exploratory Design, and Embedded Design (Creswell & Plano Clark, 2007, Plano Clark & Creswell, 2008). The Embedded Mixed Methods Design is applicable when the objective of the research is experimental, or when the researcher is looking for correlations (Creswell & Plano Clark, 2007).

Research Design

The research design utilized in this study was an Embedded Quasi-Experimental Mixed Methods Design Model as shown in Figure 1. According to Creswell and Plano Clark (2007), using this design is effective when a single data set, quantitative or qualitative, is not sufficient in answering the research questions. They state "this design is particularly useful when a researcher needs to embed a qualitative component within a quantitative design, as in the case of an experimental or correlation design" (p. 67). The combinations of the methodologies of quasi-experimental research (Sealander, 2004) along with case study research (Yin, 2009) were the components of this design.

Sealander (2004) defines experimental research as being research that answers a question concerning a relationship between a treatment and a change in the behavior of an individual. Johnson and Onwuegbuzie (2004) mention many strengths of experimental research. With respect to the research problem

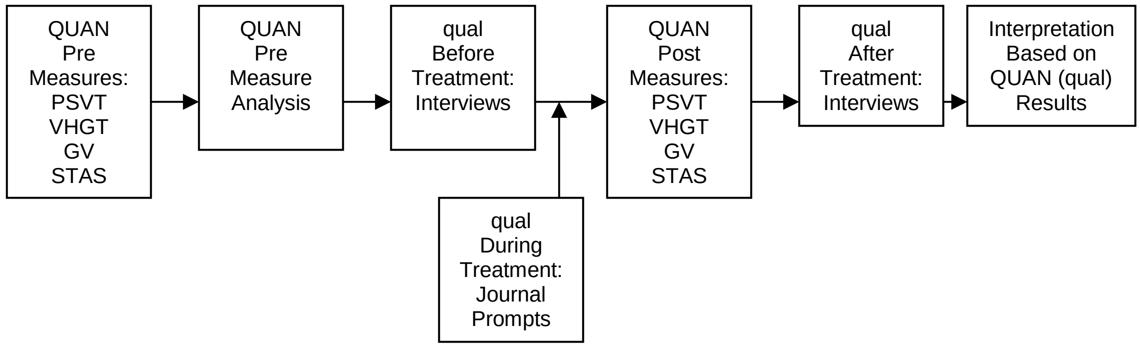


Figure 1. Synopsis of the embedded quasi-experimental mixed methods design.

currently being addressed, one strength was that data collection and data analysis were relatively time efficient, allowing for a large number of pre-service teachers to be studied. Another strength was that the data were unambiguous numbers, and the results with respect to the statistical analyses of the measurement of spatial thinking, geometric thinking, and attitudes regarding spatial thinking could be generalizable to other larger populations of pre-service elementary teachers.

The limitation of only using experimental research for this study is that it fails to answer whether or not a phenomenon exists. As Yin (2009) emphasizes, an experiment concentrates on a few variables, which results in the dissociation of the phenomenon from its context. This equates to the fact that the information obtained using just experimental research may be too abstract to make any connections as to empower the learning process and inform educational policy with respect to pre-service elementary teachers and their spatial and geometric thinking, which, as pointed out by Cross and Belli (2004), is the main goal of experimental research.

Yin (2009) points out that case study research is appropriate when answering a research question that asks “how” and he defines case study research as: “an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident” (p. 18). Merriam (1998) relates that the distinction of case study research is that the focus of the study, which is the case, is a bounded, integrated system. Altogether, case study research is bounded in context and seeks to explore and understand an event through multiple data sources. In this particular instance, the classroom, instructor, and the elementary pre-service teachers’ beliefs regarding spatial thinking and geometric thinking bound this case study research. Add in the influential nature of the *Quick Draw* activity with respect to those beliefs and together, the integrated, enclosed system is formed. Conducting research in this mixed methods fashion allowed a more in-depth understanding, leading to increased meaning of the influence of *Quick Draw* with regard to pre-service teachers spatial and geometric thinking along with their spatial thinking beliefs.

One weakness of only looking at case study research would be that qualitative data alone would not be able to show correlations regarding the influence of the *Quick Draw* activity with respect to the pre-service elementary teacher’s geometric thinking and spatial thinking experiences. Secondly, the interview data collection and data analysis is time intensive, therefore limiting the number of participants, which would tend to make the results less generalizable (Johnson & Onwuegbuzie, 2004).

The combination of the strategies, quasi-experimental research with case study research through an embedded quasi-experimental mixed methods design, was a good fit with respect to exploring the relationships between pre-service elementary teachers' geometric thinking and spatial thinking experiences as they related to the *Quick Draw* activity. The strengths individually remain strengths when they are joined and their union dilutes their individual weaknesses. Uniting these strategies allows the opportunity for a multifaceted interpretation of findings (Shutz, Chambless, & DeCuir, 2004). These strategies compliment each other. The perceptions of the pre-service elementary teachers will add depth to the results that have been obtained from the statistical analysis. Additionally, the results, instead of being a dead end, could give direction to further research in the area of spatial thinking and geometric thinking or they may provide the opportunity to further investigate any contradictions that may have been exposed as an outcome of the research.

Participants and Instructional Setting

The participants in this study consisted of 60 pre-service elementary teachers who were enrolled in the researcher's Structures of Mathematics classes. Due to the fact that quantitative data was collected every day the classes met for the first week of class and also the sixteenth week of class, and qualitative data was collected from the treatment group periodically throughout the remaining semester, the sample size of 60 fluctuated due to participant absences. Structures of Mathematics is one of four mathematics content courses required of elementary education majors. The course is an introduction to the basic concepts of arithmetic and elementary mathematics in number and operation. These pre-service elementary teachers attended a mid-sized university situated in the Midwestern United States. Although the sample, being one of convenience, implies that the pre-service elementary teachers were not selected at random, both classes were invited to participate and only those who volunteered, following IRB protocol, (see Appendix A) were included in the study. The demographic survey (see Appendix B) was obtained from each of the participants and a synopsis of the information obtained can be seen in Table 1. Additional information obtained from the demographic survey with respect to childhood activities showed that 86% of the participants reported they played with dolls, stuffed animals, or some type of action figure, 34% did some type of building such as Lego’s or blocks, 37% enjoyed playing sports or playing outside, only 8% stated that they played games or puzzles, 71% described playing a variety of video games and 63% reported playing an assortment of computer games.

The Structures of Mathematics course was chosen because there are no geometry topics covered in this particular course with the intention that the interpretations of the results of the study would not be confounded by extraneous factors. Course content included problem solving, sets, whole numbers, systems of numeration, number theory, fractions, ratios, decimals, and percents. Apart

Table 1

Demographic Information

	Treatment Group	Control Group
N	30	30
Age		
Mean	22.73	24.67
Standard Deviation	6.98	9.95
Range	18-46	18-58
Gender		
Female	90.0%	93.3%
Male	10.0%	6.7%
Race		
Caucasian	93.4%	76.8%
African American	3.3%	3.3%
Hispanic	0%	10.0%
Native American	3.3%	3.3%
Asian	0%	3.3%
Other	0%	3.3%
College Major		
Early Childhood Ed.	30.0%	23.3%
Elementary Ed.	63.4%	46.7%
Special Education	3.3%	26.7%
Other	3.3%	3.3%

	Treatment Group	Control Group
Classification		
Freshman	23.3%	24.1%
Sophomore	20.0%	34.5%
Junior	56.7%	34.5%
Senior	0.0%	6.9%
High School Geometry	96.7%	83.3%
Foundations of Geometry	23.3%	16.7%

from the introduction of a few manipulatives such as base 10 blocks and multi-base cubes to enhance the study of place-value, fraction circles, and Cuisenaire rods to enhance understanding of rational numbers, the course content was void of geometric topics and did not include any topics that would necessarily encourage the development of spatial thinking skills.

The fact as to whether the participants had taken high school geometry or Foundations of Geometry and Measurement was noted, but was ascertained to not be of importance since any changes to a student's spatial and geometric thinking incurred throughout the semester would be assumed to be with respect to the participants' initial level of spatial and geometric thinking recorded at the beginning of the semester. However, there were initially five participants involved in the study that were concurrently taking the Foundations of Geometry and Measurements class, two in the treatment group and three in the control group. Concurrent enrollment in this geometry class could possibly be seen as being a confounding variable due to the relationship between the course content of the Foundations of Geometry and Measurements class and spatial and geometric thinking; therefore, these five participants were eliminated from the study.

There were two classes of participants, one class was designated as the control group and the other class was designated as the treatment group. Taking into consideration the class meeting times made the decision as to the designation of these two groups. The treatment group was chosen because they were scheduled to meet twice a week with one hour and fifteen minute class periods; the control group was scheduled to meet three times a week with fifty-minute class periods. The researcher thought the integration of the *Quick Draw* activity would be assimilated easier into the longer class time. The control group was given all pre- and post-quantitative measures, while the treatment group was given pre- and post- quantitative measures as well as qualitative measures, along with the implementation of the treatment, the *Quick Draw* activity. One benefit of having a control group is that if there is a significant increase in mean scores on spatial and geometric instruments in the treatment group but not the control group, then the chance that these differences were due to the math content covered in the Structures of Mathematics course could possibly be eliminated.

There were four purposively sampled participants who took part in pre- and post-interviews. The four female interview participants were all Caucasian, elementary education majors. Each had taken high school geometry, although none had taken the Foundations of Geometry and Measurement class required for their major. Trixie and Piper reported making a “B” in high school geometry while Kathryn and Summer reported making an “A” in the class. Summer, Trixie, and Piper were classified as juniors, while Kathryn was a sophomore. Additionally, Summer, age 20, Kathryn, age 20, and Piper, age 21, were considered to be traditional students, while Trixie, age 46 was considered to be a non-traditional student. Trixie had obtained a business degree as a traditional student, married, had children, and was now returning to school to obtain a teaching degree. All of the participants reported playing with dolls or stuffed animals as children. Trixie and Summer also reported playing with building blocks and Lego’s respectively. Summer and Kathryn reported playing with both video games and computer games, while Piper reported playing only computer games, and Trixie responded that she had not played computer or video games.

Intervention

The treatment class received the intervention, the *Quick Draw* activity. *Quick Draw* activities were developed by Grayson Wheatley (2007), and consist of a figure with a variety of embedded geometric shapes (see Figures 2 and 3). The figure was shown to the pre-service elementary teacher for approximately three seconds via overhead projector or document camera; the figure was then removed from their sight and they were asked to draw the figure from memory by use of spatial structuring skills. If need be, the pre-service elementary teachers may have a second or third three-second look. Then, through questions such as “What did you see?”, “How did you see this?”, “What did you see first?”, and

“What did you draw first?” the pre-service teachers shared their responses through class discussion. Typical discussions focused on how the pre-service elementary teacher saw the shape, as a two- or three-dimensional shape, as related through their descriptions referring to the shape as a rhombus as opposed to a cube. A by-product of this discussion included the use of the geometric vocabulary of shape names, shape attributes, and properties of shape. Another focus of discussion was how the pre-service elementary teacher drew the figure, typically either in a part-to-whole or whole-to-part description. Those pre-service elementary teachers who shared their drawing ideas gave insight to those who had struggled with the drawing aspect of the activity. Eighteen Quick Draws were completed over a time span of eleven weeks. Each activity took approximately five minutes to complete and was initially done at the end of the class period. After the first few weeks participants started equating the *Quick Draw* activity to mean that class was over and participation in the discussion aspect of the activity started to decrease. Once this pattern was discovered the activity was then implemented approximately forty minutes into the seventy-five minute class. Lack of discussion participation was no longer a problem.

Data Collection

Data were collected sequentially throughout sixteen weeks of the seventeen-week semester. There was a combination of quantitative and qualitative data collected with the expectation that both sets of data would combine their strengths and result in obtaining more rigorous analyses with respect to answering the research questions.

Quantitative Measures

The Purdue Spatial Visualization Test. The Purdue Spatial Visualization Test (PSVT), developed by Bodner and Guay (1997), is comprised of three parts: Developments, Rotations, and Views (see Appendix C). This instrument was chosen because it is a measure of three different aspects of spatial thinking ability. The Developments section (PSVT/DEV) consists of twelve questions and measures an individual's spatial structuring skills, the Rotations section (PSVT/ROT) consists of twelve questions and measures an individual's mental rotation ability, and the Views section (PSVT/VIEW) consists of twelve questions and measures an individual's spatial perception. In this study each of these sections is seen as measuring a unique aspect of spatial thinking and analysis will focus on each individual section of the PSVT. The PSVT has been found to be a reliable instrument with Kuder-Richardson-20 (KR-20) coefficients of internal consistency being reported as .87, .89, and .92 respectively for each section (Guay, 1980). Each of the individual subtest raw scores ranged from 1 to 12. Documented permission to use this test can be found in Appendix D.

The Van Hiele Geometry Test. The Van Hiele Geometry Test (VHGT) measures the geometric developmental level of an individual. This test(see Appendix E) was created for The Cognitive Development and Achievement in Secondary School Geometry (CDASSG) Project (Usiskin, 1982) and consists of twenty-five questions, five questions for each of the five developmental van Hiele levels. The reliability of the VHGT is questionable with Kuder-Richardson-20 coefficients for each subtest being at best .39, .55, .56, .30, and .26 (Usiskin, 1982, p. 29). Subsequently, KR-20's were performed on the pre-test data for this research and were found to be .33, .34, .45, .34, and .04 respectively. Usiskin (1982) speculates the values are low because there are only five questions in each subtest; each subtest represents one of the five van Hiele levels. Permission to use this test is granted by the author, Dr. Zalman Usiskin (see Appendix D), who in turn keeps a record of all requests and research findings. To date, Dr. Usiskin has a list of fifty-seven studies in which the VHGT has been used as the van Hiele measure. Apart from using an interview protocol to measure geometric developmental level, which would be a daunting task for 70 participants, the VHGT is the only other viable choice at this time.

The van Hiele level I, recognition of shapes is a nonverbal level and is very dependent on visual processing (Van Hiele, 1999). Although, as the van Hiele levels increase there becomes a decreased emphasis on visual processing skills with an increased emphasis on verbal/propositional knowledge (Clements & Battista, 1992); level II being the analysis of component parts of figures and level III being relationships between geometric figures. With this in mind, this research looked at not only the VHGT score at which the participant begins and ends the study but also focused on any changes which occurred in the lower van Hiele levels I-III, which were represented by the first three subtests, questions 1-15, of the VHGT.

The scoring for the VHGT was done using the format designed by

Usiskin (1982). The first five questions that constitute level I (test items 1-5) are scored, if at least three of the five are correct then a score of 1 is assigned, if three out of five responses are not correct then a score of 0 is assigned. The next five questions that constitute level II (test items 6-10) are scored using the same criteria and if three out of 5 questions are correct then a score of 2 is assigned, if three out of five responses are not correct then a score of 0 is assigned. Scoring continues in this fashion with 4 points assigned for meeting the criteria of level III (test items 11-15), 8 points assigned for meeting the criteria of level IV (test items 16-20), and 16 points assigned for meeting the criteria for level V (test items 21-25). The scores for each level were added and the total score for the VHGT ranged from 0 to 31.

The Spatial Thinking Attitude Survey. The Spatial Thinking Attitude Survey (STAS) is a fifteen-question, five-point, Likert-type survey (see Appendix F). The first aspect of the survey measures beliefs regarding spatial thinking and the second aspect of the survey deals with confidence regarding mentally picturing and drawing two and three-dimensional shapes. The researcher developed this instrument. The inception of the STAS began with researching other established instruments that were similar in terms of measuring the specific desired outcomes of confidence and beliefs (Utley, 2007; Fennema & Sherman, 1976; Schoenfeld, 1983) and consequently, the STAS was then developed through a Sequential Exploratory Mixed Methods study (Hanlon, 2009). Reliability statistics show the STAS to have a coefficient alpha of 0.877. The scale used for the responses was as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 =

agree and 5 = strongly agree. The possible range of raw scores for the STAS was from 15 to 75.

Qualitative Measures

Case study research seeks to understand a phenomenon through multiple sources of data. Merriam (1998) proposes three types of data collection techniques for case study research, interviews or participant observations, analyzing document text, and field observations. Interviews and analyzing document text were utilized in this study along with field observations.

Written Responses. For the first implementation of the *Quick Draw* activity, the pre-service elementary teachers were asked to write their responses to the *Quick Draw* activity on paper (see Appendix H) before they discussed them out loud with each other. As part of this pre-written response, the participants were asked to draw the *Quick Draw* figure (see Figure 2) and write out answers to the following questions, “What did you see first?”, “What else do you see?”, and “How do you feel about your representation of the *Quick Draw* as compared to the actual *Quick Draw*?” In the weeks that followed the *Quick Draw* activity was completed as to the author’s intended protocol, as a group activity ensued with class discussion. Having the pre-service elementary teachers write their responses on paper before they discussed them out loud as a class was also completed during the last implementation of the *Quick Draw* activity as the post-written response. The same *Quick Draw* figure (see Figure 2) was used in both the pre- and post-written responses. The written response data collected

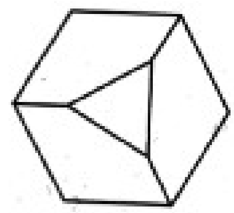


Figure 2. Quick draw figure implemented as a pre and post written response.

provided the researcher with a more in depth understanding of how the pre-service elementary teachers adeptness to the *Quick Draw* activity had evolved over the span of the semester.

Journal Prompts. Three journal prompts (see Appendix I) were administered to aid in the understanding of the pre-service elementary teachers transformed perceptions of their spatial, and geometric thinking throughout the implementations of the *Quick Draw* activities. The first journal prompt,

> “What are your first thoughts when you are asked to draw geometric figures such as those in the Quick Draw activity? Please explain.”

was administered at the end of week seven after the participants had completed eight *Quick Draw* activities. The second journal prompt,

> “How comfortable are you with geometric vocabulary and identifying geometric shapes accurately? Please explain.”

was administered at the end of week twelve after thirteen *Quick Draw* activities had been completed. The final journal prompt included multiple questions,

1. “Do you feel your spatial thinking skills have improved throughout the

semester? Please explain."

2. "Do you feel your ability to draw geometric figures has improved throughout the semester? Please explain."
3. "Do you feel your geometric vocabulary has improved throughout the semester? Please explain."
4. "Do you feel your ability to see a variety of geometric figures embedded in the Quick Draw activities has increases throughout the semester? Please explain."
5. "If you responded yes to any of the questions above, what might you attribute this improvement to? Why? Please explain."

This third prompt was administered the fifteenth week of the semester after seventeen *Quick Draw* activities had been employed. In retrospect, it is duly noted that the question "Do you feel your ability to see a variety of geometric figures embedded in the Quick Draw activities has increases throughout the semester? Please explain." Is ascertained to be a leading question.

Interviews. Interviews are typically the richest resource of data collection in case study research because they provide in depth information from diverse viewpoints (Hayes, 2004). Semi-structured interviews (Rubin & Rubin, 2005) between pre-service elementary teachers and the researcher were audio taped. Participants consisted of four pre-service elementary teacher volunteers from the treatment group. The selections were done using purposive sampling based on selecting participants who were at different levels of spatial and geometric thinking abilities as to gain a variety of perspectives and insights. Participants

Table 2

Selection of Interview Participants

	Low Spatial Ability PSVT Scores 6-11	High Spatial Ability PSVT Scores 15-21
Low Geometric Thinking VHGT Score of 1	Piper	
High Geometric Thinking VHGT Scores 7-24	Trixie Summer	Kathryn

from each of four categories were solicited, low spatial ability/low van Hiele level, low spatial ability/high van Hiele level, high spatial ability/ low van Hiele level, and high spatial ability/high van Hiele level (Table 2). However, no participants that fit into the high spatial ability/low van Hiele level category volunteered to be interviewed.

The low-high rankings in spatial ability were obtained from the results of the PSVT pre-measure, and the low-high rankings with respect to van Hiele level were obtained from the VHGT pre-measure, for this treatment group. In both instances, quartiles were calculated using SPSS statistical software and a low ranking was any score that fell in the 1st quartile and a high ranking was any score that fell in the 4th quartile. Using quartiles to determine cut scores is common practice, for instance the state of Nevada makes use of this process in their assessment program (Cronin & Bowe, 2004). The benefit to using cut scores for standard setting is that this process ensures the high/low classifications are determined in an objective and defensible manner (Cizek & Bunch, 2007).

The semi-structured pre-interview protocol (see Appendix G) consisted of three topics: past and present spatial thinking experiences, past and present geometric thinking experiences, and beliefs regarding spatial and geometric thinking. The interview data were obtained in order to give the researcher a more in-depth appraisal of pre-service elementary teachers with respect to spatial thinking, geometric thinking and beliefs regarding spatial and geometric thinking. The semi-structured post-interview protocol, apart from spatial and geometric thinking focused on the pre-service elementary teachers' views regarding the *Quick Draw* activity.

Mixed Measures

The Geometric Vocabulary test. The Geometric Vocabulary test (GV) was developed by the researcher and consisted of a picture of a complex geometric *Quick Draw* figure (Figure 3) and required the pre-service elementary teacher to list all of the geometric terms and geometric shapes that could be viewed in the figure (see Appendix J). Although this test was researcher developed, it was based upon a procedure outlined by Wheatley (2007) who used this particular *Quick Draw* figure with a class of elementary school students and found that these students named a total of fourteen geometric shapes and terms. A list of potential geometric shapes and terms for the GV as identified by two university

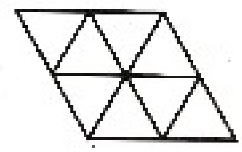


Figure 3. Quick draw figure found on the geometric vocabulary test.

mathematics professors can be seen in Appendix J. This particular data was analyzed both as a quantitative and qualitative measure to more thoroughly examine the pre-service teachers geometric vocabulary.

As a quantitative measure, the score was determined by assigning one point for each correct vocabulary word used. No points were assigned for the word diamond; preference was given to the more technically accurate term of rhombus. The KR-20 reliability associated with this test was found to be low (KR-20 = 0.532); although upon two administrations of the GV, test-retest reliability (measured through the pre-test and post-test of the control group) was determined through the significant correlation ($r = .529, p = .000$). As a qualitative measure, the geometric shapes and terms listed in the pre-test were compared to those reported in the post-test for the treatment group.

Trustworthiness

Although qualitative research is not judged using statistical tests that measure validity and reliability, as are quantitative instruments, Lincoln and Guba (1985) have proposed four criteria to guide the trustworthiness of qualitative research. Credibility was accounted for by means of the research design and the implementation of the research design. Included in this aspect is the fact that data was obtained from multiple sources (triangulation), and through member checking with respect to the interviewees. Transferability of the conclusion of meaning and value of the results of this study, as with any case study research, is left to the discretion of the reader (Hayes, 2004). Dependability was accounted for through an audit trail (Merriam, 2004) by means of detailed explanations of data collection and data analysis in that by coding, developing themes and organizing these themes by use of a matrix, the researcher is providing assurance that the reconstruction of the participants' views have been accurately portrayed. Confirmability was established through the union and or comparison of the qualitative results ascertained with respect to the quantitative results obtained in this embedded quasi-experimental mixed methods design study.

Procedure

After obtaining IRB approval (see Appendix A), the study was carried out in five phases (see Table 3). The first phase consisted of a colleague of the researcher explaining the purpose of the research to both groups of pre-service elementary teachers in the control and treatment Structures of Mathematics classes. Overall, there were two sampling strategies utilized. The overarching sample of the study was that of a convenience volunteer sample (Teddlie & Yu, 2007). A sample of convenience implies that the pre-service elementary teachers were not selected at random, but were easily accessible as they were enrolled in the researchers classes. These two Structure of Mathematics classes were invited to participate in the study and only those pre-service elementary teachers who volunteered were included in the study. Following the protocol of the IRB, to ensure participants did not feel pressured into participation, a colleague facilitated the collection of the informed consent forms along with the collection of all of the rest of the data, with the exception of the interviews, in the absence of the researcher. The colleague was asked to read the researcher's dissertation proposal, was then instructed by the researcher before each interaction with the participants, and was given a script to follow for each interaction with the participants.

Data collection during phase one consisted of both classes being given the demographic survey, PSVT, VHGT, GV, and the STAS during the second week of classes. These pre-test measures were analyzed to determine if there were any significant differences between the two groups. Once it was determined that there were no significant differences between the two groups, the data for the two groups was combined and was analyzed to determine if there were any correlations between the PSVT, VHGT, GV, and STAS measures.

The second phase of data collection for the study took place during the third and fourth week of classes and was comprised of interviewing four pre-service elementary teachers before the *Quick Draw* treatment began. These participants were selected from the treatment group. The selections were done using purposive sampling due to the fact that the researcher was interested in obtaining participants who were at different levels of spatial ability and geometric

Table 3

Synopsis of a Semester of Data Collection

	Phase 1: Week 2	Phase 2: Weeks 3-4	Phase 3: Weeks 5-15	Phase 4: Week 16	Phase 5: Week 17
Treatment Class	*Demographic *PSVT *VHGT *GV *STAS	*Interviews	*Written Response *Journal Prompts	*PSVT *VHGT *GV *STAS	*Interviews
Control Class	*Demographic *PSVT *VHGT *GV *STAS			*PSVT *VHGT *GV *STAS	

thinking to increase transferability or generalizability of results with respect to specific contexts (Teddlie & Fu, 2007). “The central idea is that if participants are purposefully chosen to be different in the first place, then their views will reflect this difference and provide a good qualitative study” (Creswell & Plano Clark, 2007, p. 112). One student from each of four categories was solicited, low spatial ability/low van Hiele level, low spatial ability/high van Hiele level, high spatial ability/ low van Hiele level, and high spatial ability/high van Hiele level. The low-high rankings in spatial ability were obtained using quartiles calculated from the results of the PSVT pre-measure of the treatment group. The low-high rankings with respect to van Hiele level were obtained using quartiles calculated from the VHGT pre-measure of the treatment group. These results had been obtained at the conclusion of phase one. Of the four categories from which interviewees were solicited, there was one category from which there were no volunteers, the high spatial ability/low van Hiele level category (see Table 2).

The third phase of the study, weeks five through fifteen, was the integration of the treatment the *Quick Draw* activity into the class meetings of the treatment group. This was accomplished by taking approximately five minutes of class time to conduct the activity. This phase of the study lasted for eleven weeks; a total of eighteen *Quick Draws* were implemented during this time. The first and last *Quick Draw* activities implemented in this phase were done first using written responses before the class discussion ensued. The written response *Quick Draw* image is pictured in Figure 2. Three journal prompts were also elicited throughout this eleven-week phase. A colleague collected the data each time in the absence of the researcher, with the exception of the interviews.

The fourth phase of the study was conducted during the sixteenth week of the semester and consisted of a colleague administering the PSVT, VHGT, GV, and the STAS post-tests to the treatment and control groups in the absence of the researcher. The post-tests for the four pre-service elementary teachers were analyzed and compared to their pre-test scores.

The fifth and final phase of the study was conducted in the seventeenth week of the semester. During this phase, post-treatment, semi-structured interviews were conducted with the four pre-service elementary teachers who had been interviewed in phase two. The follow-up interviews (see Appendix G) focused on the *Quick Draw* activity with respect to spatial thinking, geometric thinking, and beliefs regarding spatial thinking. This allowed the researcher to see any changes in participants understanding and perspectives along with their reaction and insights to the *Quick Draw* activity.

Data Analysis

The quantitative data were analyzed using statistical methods by means of SPSS and SAS computer software to determine whether the implementation of the *Quick Draw* activity significantly influenced pre-service elementary teachers spatial thinking, geometric thinking, and attitudes regarding spatial thinking. There were various aspects with regard to analyzing the quantitative data. The first aspect addressed the importance of both the treatment and control groups starting the study at the same level. To determine that there were no significant differences between the treatment and control groups at the beginning of the study, independent sample t-tests were performed on the quantitative data, the PSVT, VHGT, and the GV. A Fisher's Exact test was used to analyze the STAS; a Fisher's Exact test is an alternative to the Chi-square test that it is used when data is scaled as in the case of the STAS, albeit, Fisher's Exact test is appropriate where sample sizes are small. Statistically significant results are those for which $p < 0.05$.

The next statistical analyses focused on finding any correlations between the four dependent variable measures (PSVT, VHGT, GV, and STAS). A Pearson's correlation coefficient was utilized to determine if measures were considered to be separate dependent variables or multiple dependent variables. This would help to determine whether an ANOVA (analysis of variance) or a MANOVA (multivariate analysis of variance) would be the appropriate statistic for future statistical analysis.

The final aspect of analyzing the quantitative data was one of the analyses of primary interest: to determine if there were control/treatment/pre/post differences across the measures of the PSVT, VHGT, GV, and the STAS. To make this determination, a 2 x 2 mixed design ANOVA was used for the pre/post measures with respect to the treatment and control groups; statistically significant results are those for which $p < 0.05$. Also of importance were the descriptive statistics: sample size, mean, standard deviation, and range.

The qualitative data were analyzed to determine whether the implementation of the *Quick Draw* activity influenced pre-service elementary teachers' spatial thinking, geometric thinking, and attitudes regarding spatial thinking. The semi-structured pre-interviews, written responses, journal prompts, and GV were analyzed using constant comparative method by means of coding using a line-by-line analysis as suggested by Strauss and Corbin (1998). The line-by-line analysis was then analyzed thematically as suggested by Patton (2001). The main themes were organized, to determine patterns by use of a matrix (Creswell & Plano Clark, 2007). The post-interviews were organized into narrative descriptions (Merriam, 2001) detailing the phenomena of how the participants viewed the influence of the Quick Draw activity with regard to their concepts of spatial thinking, geometric thinking, and spatial thinking beliefs.

Ethical Considerations

Following the IRB protocol, all participants received an assurance of privacy and confidentiality as part of the informed consent process. To ensure privacy, all participants' responses were coded and pseudonyms were used. Additionally, considering the participants were all enrolled in the researchers classes, a third party was utilized for collecting informed consents as well as all of the data in the absence of the researcher, with the exception of the interviews.

Summary

The following break down equates each research question with its related mode of analysis.

- *Does the integration of Quick Draw activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for pre-service elementary teachers?* First, independent samples t-tests, or Fisher's Exact tests were used to analyze the control and treatment groups' pre-tests to assure that there were no significant differences between the two groups. A Pearson's correlation coefficient was utilized to determine which of the measures were related so as to indicate what further statistical analyses were performed. Pre- and post-measures of the VHGT, STAS, PSVT, and GV were examined using 2 x 2 mixed design ANOVA's; descriptive statistics such as sample size, mean, standard deviation and range were also obtained.

- *How does the integration of Quick Draw activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?* Written responses, journal prompts, semi-structured interviews, and the GV were analyzed through line-by-line analysis by means of the constant comparative method through use of coding to establish emergent themes and determine patterns.
- *How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?* Journal prompts and semi-structured interviews were analyzed through line-by-line analysis by means of the constant comparative method through use of coding to establish emergent themes and determine patterns.

The data analysis results can be found in Chapter IV followed by the discussion of the findings in Chapter V.

CHAPTER IV

RESULTS

This embedded quasi-experimental mixed methods study gathered both quantitative and qualitative data from pre-service elementary teachers for the purpose of understanding the influence of an activity called *Quick Draw* with respect to their spatial and geometric thinking, beliefs regarding spatial thinking, and their general awareness of spatial and geometric thinking. This chapter provides an accounting of the data acquired from the pre/post geometric thinking, spatial thinking, and spatial thinking beliefs instruments, along with the data garnered from written responses, journal prompts, and semi-structured interviews. The research questions guiding this study were:

- Does the integration of *Quick Draw* activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for pre-service elementary teachers?
- How does the integration of *Quick Draw* activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?

- How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?

This chapter is presented in five key sections. The first section will be devoted to the quantitative analysis of the pre-test instruments and will describe any pre-test differences found between the treatment and control groups, along with any correlations found between the dependent variables, the Van Hiele Geometry Test (VHGT), the Geometric Vocabulary test (GV), the Purdue Spatial Visualization Test Developments section (PSVT/DEV), Rotations section (PSVT/ROT), Views section (PSVT/VIEWS), and the Spatial Thinking Attitude Survey (STAS). The next three sections will address both quantitative and qualitative findings by combining the first two research questions from each topic of geometric thinking, spatial thinking, and spatial thinking beliefs. Specifically, the second section presents the quantitative and qualitative aspects of the influence of the activity *Quick Draw* with respect to geometric thinking. Similarly, the third and fourth sections are devoted to the quantitative and qualitative aspects of the *Quick Draw* activity as it relates to spatial thinking and then to spatial thinking beliefs respectively. The fifth section will focus on the qualitative analysis of the third research question. This final section portrays the views of the pre-service elementary teachers as they relate to spatial and geometric thinking.

Pre-Test Analyses

Initial quantitative analyses were run on the pre-test data to determine what the appropriate quantitative analyses would be to address the first research question. The first aspect of the pre-test analyses was to determine if there were any significant differences between the treatment group and control group at the beginning of the semester. This was accomplished using independent sample t-tests on SPSS computer software. There were no significant differences found between the treatment group and control group based on the mean scores of participants' age, VHGT, and PSVT pre-tests. The Independent sample t-test revealed that there was a significant difference ($t = 1.255, p = .018$) between the control group ($n = 30, M = 4.300, SD = 2.351$) and treatment group mean scores on the GV ($n = 22, M = 3.046, SD = 1.290$). Similarly, the SAS computer program was used to run Fisher's Exact Test to determine that there were no significant differences between the treatment and control groups at the beginning of the semester on the STAS pre-test, and the demographic characteristics of gender, race, major, classification, and whether they had high school geometry, or had Foundations of Geometry and Measurement. A Fisher's Exact test is an alternative to the Chi-square test and is used when sample size is small. Fisher's Exact and Chi-square statistical tests are utilized when data is scaled, as in the case of the STAS, or dichotomous, as is the case of the demographic information.

The second aspect of the initial qualitative analyses was to determine if there were any correlations between the dependent variables: VHGT, GV, PSVT/DEV, PSVT/ROT, PSVT/VIEWS and the STAS. Since the only significant differences between the two groups was with the GV, as noted previously, the two groups were combined and SPSS was used to run Pearson's correlations

Table 4

Pre-Test Analysis: Pearson's Correlations

	VHGT	GV	STAS	PSVT/DEV	PSVT/ROT	PSVT/VIEW
VHGT	-	.343*	.286*	.030	.256	.006
GV		-	.267	-.308*	-.205	-.230
STAS			-	-.038	.159	.103
PSVT/DEV				-	.246	.100
PSVT/ROT					-	.293
PSVT/VIEW						-

Note. Van Hiele Geometry Test = VHGT, Geometric Vocabulary Test = GV, Spatial Thinking Attitude Survey = STAS, and the Purdue Spatial Visualization Test Developments Section = PSVT/DEV, Rotations Section = PSVT/ROT, and Views Section = PSVT/VIEW.

*Correlation is significant at the $p < .05$ level (2-tailed).

to determine if there were any correlations between the dependent measures. There were significant correlations found between the GV and the VHGT ($r = .343, p = .026$), the VHGT and the STAS ($r = .286, p = .049$), and also the PSVT/DEV and the GV ($r = -.308, p = .039$) as shown in Table 4. Taking into consideration the fact that the GV and the VHGT were both a type of measure of geometric thinking, it was decided that although some of the dependent measures were intercorrelated, that the quantitative analyses of the first research question would be handled with analyses of variance (ANOVA) as opposed to multivariate analyses of variance (MANOVA). The rationale behind this decision was similar to that used in Fennema and Sherman's (1977) research in which they state, "Univariate ANOVAS were used instead of multivariate analyses of variance (MANOVA) because it was felt that a MANOVA might obscure significant results with the individual variables. Although the variables were intercorrelated, each variable was conceptualized as uniquely important" (p. 58).

The *Quick Draw* Activity and Geometric Thinking

The Van Hiele Geometry Test (VHGT)

The VHGT (Usiskin, 1982) was one of two tests employed to measure geometric thinking. This was a twenty-five question, multiple-choice test with five questions pertaining to each of the five van Hiele levels (see Appendix E). Using SPSS computer software the descriptive statistics of sample size, mean, standard deviation, and range were obtained for the VHGT, along with the results of a 2 x 2 mixed design ANOVA (see Table 5). The ANOVA revealed that although there was a statistically significant result ($F = 5.561, p = .024$), found in the interaction of time (pre-test, post-test) and group (treatment, control), there were no statistically significant differences in mean scores of the VHGT with regard to the main effect of time ($F = 2.809$, $p = .102$) and no statistically significant differences in mean scores of the VHGT with regard to the main effect of group ($F = 1.135$, $p = .294$).

Of the five van Hiele levels, it is posited that the *Quick Draw* activity has the propensity to have more of an influence on the lower three levels: recognition, analysis, and relationships. The van Hiele level I, recognition of

Table 5

Test Descriptive Statistics and Analysis of Variance Results for the Van Hiele Geometry Test

	n	M		SD		Range	
		Pre	Post	Pre	Post	Pre	Post
Treatment	25	5.26	2.36	5.28	1.45	1-24	1-31
Control	19	10.43	5.79	10.78	5.59	1-25	0-23

Source	SS	df	MS	*F*	*p*	$\hat{\omega}^2$
	Between	subjects				
Group (G)	104.027	1	104.027	1.135	.294	.003
Error	3391.435	37	91.660	2.809	.102	.044
	Within	subjects				
Time (T)	87.191	1	87.191	5.561	.024*	.105
T X G	172.627	1	172.627			
Error	1148.527	37	31.041			

Note. Time = pre-test, post-test, Group = treatment, control.

*Significant at the $p < .05$ level.

shapes, is a nonverbal level and is very dependent on visual processing. Level II relates to the analysis of component parts of figures and level III pertains to the relationships between geometric figures (van Hiele, 1999). With this in mind, apart from the VHGT raw score, any changes that occurred in the lower van Hiele levels I-III, which were represented by the first three subtests, questions 1-15 of the VHGT, would be of interest. To explore this aspect of the VHGT, a subset of the data, that only included those students from the control and treatment classes whose VHGT pre-test scores were less than 7 (VHGT < 7), were analyzed to see if there were any significant differences in mean scores with respect to these lower van Hiele levels. Using SPSS computer software the descriptive statistics of sample size, mean, standard deviation, and range were obtained for the VHGT < 7, along with the results of a 2 x 2 mixed design ANOVA (see Table 6). The ANOVA showed that the time (pre-test, post-test) and group (treatment, control) interaction was non-significant ($F = .558$, $p = .463$), and additionally, that there were no significant differences in mean scores of the VHGT < 7 for the main effect of group ($F = 2.809$, $p = .102$). However, there was a significant difference in mean scores of the VHGT < 7 for the main effect of time ($F = 6.884$, $p = .015$). These results suggest that both the treatment group ($M_{pre} = 2.36, M_{post} = 5.79$) and the control group ($M_{pre} = 1.82, M_{post} = 3.73$) mean pre-test score of VHGT less than 7 increased significantly.

Additionally, a subset of the VHGT that included the Van Hiele Geometry pre-test scores greater than 7 (VHGT > 7) was also analyzed using a 2 x 2 mixed design ANOVA. This analysis revealed that although the time x group interaction was significant ($F = 6.434$, $p = .026$), there were no statistically significant differences in mean scores of the VHGT > 7 with regard to the main effect of time ($F = 0.023$, $p = .882$) and no statistically significant differences in mean scores

Table 6

Descriptive Statistics and Analysis of Variance Results for the Van Hiele Geometry Pre-Test Score Less Than Seven

	n	M		SD		Range	
		Pre	Post	Pre	Post	Pre	Post
Treatment	14	5.94	1.82	7.52	1.66	1-5	1-17
Control	11	5.06	3.73	5.91	3.95	0-5	0-14
Source	SS	df	MS	*F*	*p*	$\hat{\omega}^2$	
	Between	subjects					
Group (G)	20.779	1	20.779	1.474	.237	.068	
Error	324.221	23	14.097				
	Within	subjects					
Time (T)	87.751	1	87.751	6.884	.015*	.191	
T X G	7.111	1	7.111	.558	.463	.000	
Error	293.169	23	12.746				

Note. Time = pre-test, post-test, Group = treatment, control.

*Significant at the $p < .05$ level.

of the VHGT with regard to the main effect of group ($F = 0.250$, $p = .626$).

The Geometric Vocabulary Test (GV)

Geometric vocabulary plays an integral part of geometric thinking. The

GV (see Appendix J) was designed from a *Quick Draw* figure that the researcher transformed into an open-ended question to measure geometric thinking with a specific emphasis on the vocabulary dealing with geometric shapes and geometric terms. Wheatley (2007) used this particular *Quick Draw* figure with a class of elementary school students and found that these students named a total of fourteen geometric shapes and terms. A list of potential geometric shapes (13) and terms (23) for the Geometric Vocabulary test (GV), as identified by two university mathematics professors, can be seen in Appendix J. The Quick Draw figure used on the GV, initially shown in the third chapter, is provided again for convenience.

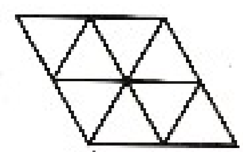


Figure 3. Quick draw figure found on the geometric vocabulary test.

This instrument was both a quantitative and qualitative measure. As a quantitative measure, assigning one point for each correct geometric shape or term listed by the participant scored the GV. SPSS was used to obtain the descriptive statistics of sample size, mean, standard deviation, and range for the GV (see Table 7). Previously, the pre-test analysis of the GV, an independent sample t-test, showed that there was a significant difference between mean scores on the GV with regard to the control and treatment group. Taking this

Table 7

Descriptive Statistics and Analysis of Variance Results for the Geometric Vocabulary Test

	n	M		SD		Range		
		Pre	Post	Pre	Post	Pre	Post	
Treatment	28	4.39	4.50	2.39	1.62	2-11	2-8	
Control	15	3.20	3.60	1.52	1.06	2-7	1-6	
Source	SS	df		MS		*F*		*p*
Group (G)	1.015	1		1.015		.566		.456
Block (B)	10.747	1		10.747		5.994		.019
G X B	.090	1		.090		.050		.824
Error	69.926	39		1.793				

Note. Block = pre-GV, Group = treatment, control.

significant difference between the treatment and control groups into consideration, and also that the intraclass correlation Eta was .365, a 2 x 2 randomized block design ANOVA revealed (see Table 7) that there were no significant differences in mean scores of the GV for the interaction of group x block ($F = .050$, $p = .824$), and no significant differences in mean scores of the GV for the main effect of group ($F = .566$, $p = .456$). Overall, these results indicate that there were no significant differences in the GV pre-test/post-test mean scores.

For the analysis of the GV as a qualitative measure, the focus was on the

Table 8

Geometric Vocabulary Test Terminology Results of the Treatment Group

	Correct	Pre (n=30)	Post (n=28)	Incorrect	Pre (n=30)	Post (n=28)
Shapes	Triangle	30	28	Rectangle	9	5
	Hexagon	14	13	Square	8	3
	Rhombus	13	22	Octagon	3	3
	Diamond	13	10			
	Parallelogram	13	22			
	Trapezoid	10	11			
	Quadrilateral	7	5			
Terms	Equilateral	7	8	Horizontal	2	-
	Polygon	6	-	Vertical	2	-
	Angle	5	2	Ninety-degrees	2	-
	Kite	4	4			
	Pentagon	3	4	Cylinder	2	-
	Parallel	3	1	Cube	1	-
	Acute	2	-	Parabola	1	-
	Diagonal	2	1	Pi	1	-
	Line	2	1	Polyhedron	1	-
	Symmetry	2	-	Right triangle	1	-
	Regular	1	-			

	Correct			Incorrect		
		Pre	Post		Pre	Post
Terms	Obtuse	1	-	Tetrahedron	1	-
	Intersecting	1	-	Prism	1	-
	Congruent	1	-	Hypotenuse	1	-
	Tessellation	1	-			
	Sixty degrees	1	-			

specific words that were listed on the participant's response sheets. The directions on the GV were explicit in stating:

"Using the following figure list all of the geometric terms and geometric shapes that you can identify."

Classification of the words resulted in three main categories: correct geometric vocabulary, incorrect geometric vocabulary, and a third in vivo category consisting of a single word, "diamond", which although it is not considered to be incorrect geometric vocabulary, it is expected that pre-service elementary teachers ideally should be able to identify this shape mathematically as a rhombus. The category of correct geometric vocabulary could be further subdivided into correct geometric shapes and correct geometric terms. The category of incorrect geometric vocabulary was also further subdivided into incorrect geometric shapes and incorrect geometric terms. The breakdown can be seen in Table 8 with words taken from the GV-pretest listed in decreasing frequency.

Overall, as depicted in Table 8, there were more geometric shapes listed than geometric terms on both the pre-GV (12 shapes, accounting for 88% of the responses) and post-GV (11 shapes, accounting for 98% of the responses). Although upon further inspection, there was a greater variety of responses of geometric shapes and terms given on the pre-GV (23 shapes and terms) as compared to the post-GV (14 shapes and terms) where there were mostly just geometric shapes listed. This indicates that, overall, the participants seemed to be more comfortable with identifying geometric shapes and more focused on finding geometric shapes as opposed to listing geometric terminology on the post-GV as compared to the pre-GV.

Due to the results of the qualitative analysis, the use of the words "diamond" and "rhombus" were further analyzed quantitatively for both the treatment and control groups using a McNemar statistical test on SAS. A McNemar test is a non-parametric statistical test used in paired comparison studies when the responses are dichotomous. The results, as seen in Table 9, showed that there was no significant difference in the use of the word "diamond" between the pre- and post-GV with regard to the control group, and there was no significant difference in the use of the word "diamond" between the pre- and post-GV with regard to the treatment group. While, there was a significant difference ($S = 9.0000$, $p = .0054$) in the use of the word "rhombus" from the pre-GV (46.43%) to the post-GV (78.57%) with regard to the treatment group. Also, there was no significant difference found with respect to the use of the word "rhombus" on the pre- and post-GV for the control group ($S = .0000$, $p = 1 .0000$). This

Table 9

Use of the Word Diamond verses Rhombus

Word	Group	N	Percent		McNemar's Test	
			Pre	Post	*S*	*p*
Diamond	Treatment	28	39.29	35.71	0.111	.739
	Control	15	46.67	53.33	0.333	.564
Rhombus	Treatment	28	46.43	78.57	9.000	.005*
	Control	15	26.67	26.67	0.000	1.000

*Significant at the .05 level (2-tailed).

suggests that the *Quick Draw* activity may in fact have helped to enhance the pre-service elementary teachers geometric vocabulary by introducing or re-familiarizing them with the geometric shape vocabulary term of rhombus.

Written Responses and Journal Prompts

The first and last *Quick Draws* were implemented as written responses (see Appendix H), meaning that twenty-four participants in the treatment group recorded their responses to the same *Quick Draw* figure (see Figure 2 from the third chapter that is provided again for convenience) as a pre/post activity on paper. In terms of analysis with respect to geometric thinking, the focus was on the geometric vocabulary the participants used to describe how they saw the *Quick Draw* figure. The majority of participants (83%) reported first seeing the triangle both on the pre-written response and on the post-written response. The

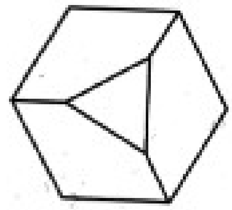


Figure 2. Quick draw figure implemented as a pre and post written response.

next most common geometric vocabulary responses included the participants seeing a cube, a box, and a square. One participant reported seeing a hexagon, and another participant reported seeing two pentagons, once again revealing the emphasis of the participant's focus being on geometric shape as opposed to geometric terminology of shape properties or shape attributes.

Since geometric thinking is prevalent in the elementary curriculum, and with the participants being prospective elementary teachers, Journal Prompt 2 (see Appendix I) which was administered after thirteen of the eighteen *Quick Draw* activities had been completed, addressed the treatment group's comfort level with respect to identifying geometric shapes and geometric vocabulary:

> "How comfortable are you with geometric vocabulary and identifying geometric shapes accurately?"

Twelve of the twenty-seven responses focused only on shapes, and of those twelve, three replied that they were "not" comfortable, four replied that they were "somewhat" comfortable, and five replied that they were "very" comfortable with identifying geometric shapes.

Seven of the twenty-seven participants elicited a generic response to the prompt with no reference to geometric shapes or geometric vocabulary. Of the seven generic responses, six said they were “not” comfortable, and one said they were “somewhat” comfortable.

Eight of the twenty-seven participants responded specifically to both the geometric shape and geometric vocabulary aspects of the journal prompt. Of those eight, five answered that they were “not “comfortable with identifying geometric vocabulary and “somewhat” comfortable with identifying geometric shapes. Two of the eight responded that they were “somewhat” comfortable with both aspects of identifying vocabulary and shapes, and one of the eight said she was “not” comfortable with identifying vocabulary, but “very” comfortable with identifying shapes. Additionally, six of the twenty-seven participants justified their responses to the journal prompt similarly to Sandy, “I’m not so great, it has been a while since I have had a geo class so it is rather tough.” Furthermore, Sue stated, “I only had 1 geometry class my entire life, which was in high school & I made a “C” in that class.” While it is difficult to quantify these results due to the diversity of the answers, the inclination appears to be that few participants appeared to be confident in their knowledge of geometric vocabulary.

On the third journal prompt, the participants in the treatment group were given the opportunity to comment on the improvement or lack of improvement of their geometric vocabulary. This prompt was administered after seventeen of the eighteen *Quick Draw* activities had been completed. The journal prompt question asked:

“Do you feel your geometric vocabulary has improved throughout the semester? Please explain."

Of the twenty-seven participants who responded to the third journal prompt, 55% believed their geometric vocabulary had improved throughout the semester, 11% replied "some," and 4 % replied "better." Two main themes arose through these participants explanations, the first being the "discussion" aspect of the *Quick Draw* activity aiding in their increased geometric vocabulary as noted by Sandy, "Yes, discussing quick draws in class made me more aware of geometric names." The second reoccurring theme was "familiarity" as indicated by Trixie's response, " Yes, just from the familiarity of seeing and identifying shapes each week." Of the breakdown of the remaining eight participants (30%) who felt as though their geometric vocabulary did not improve throughout the semester, three participants felt secure in their previous knowledge of geometric terminology. As Paula states, "Not necessarily, but I feel as if I was pretty good at the beginning of the semester." Also, Naomi points out, "I had geometry and measurement last semester so I knew the vocabulary from that class." The remaining five participants expressed explanations similar to Beth, "No, I've really not used it any more or less." Additionally, 26% of the responses to this prompt mentioned the word "shape" specifically in reply to a question that had asked about geometric vocabulary in general.

Overall, the majority of the participants (70%) indicated they felt as though their geometric vocabulary had improved throughout the semester and attributed this change to either actual participation in class discussion or from listening to the class discussion. The underlying premise being the class discussions were those that resulted from doing the *Quick Draw* activity. In actuality, of the twenty-eight participants in the treatment group, 46% of their scores on the GV did increase. Of the fourteen participants in the treatment group who initially scored less than 7 on the VHGT, 56% also saw an increase in their VHGT score.

Semi-Structured Post-Interviews

One of the focal points of the semi-structured post-interviews was how the four interview participants viewed the influence of the *Quick Draw* activity with respect to their geometric thinking. Kathryn's score of 7 on the VHGT remained the same on both the pre- and post-tests, and her GV score increased by one point from a 5 on the pre-GV to a 6 on the to post-GV. Kathryn's thoughts regarding the influence of the *Quick Draw* activity with respect to her geometric thinking focused on her increased ability to see the figures as two-dimensional as opposed to three-dimensional. In seeing the figures as two-dimensional, she found they were not only easier to draw but also this two-dimensional perspective helped to refresh her memory with respect to the geometric shape vocabulary associated with the two-dimensional figures, "There were a couple (shapes), like trapezoid. For the life of me I could not remember that at the beginning of the semester and then when somebody said it, I was like, that's it! I remembered it was a shape but I could not remember what shape it was." Trapezoid was the one additional word found on Kathryn's post-GV that was not on her pre-GV. Kathryn also commented that she had wished the discussions that followed the drawing of the *Quick Draw* figure were "more in depth". She would have preferred spending more time discussing attributes and “dimensions” of shapes in addition to naming them. Unfortunately for Kathryn, the focus of the class discussions were in fact the finding and naming of the shapes as dictated by the direction the class steered the discussion.

Trixie’s VHGT score increased from a 7 to a 31, and her GV score decreased from an 11 to a 5. Trixie had responded to the third journal prompt by saying that she had thought her geometric vocabulary had improved throughout the semester due to “familiarity.” After giving Trixie a chance to examine her pre- and post-GV she came to this conclusion, “I’ll bet you anything I just went right over that (pointing at the directions) and went right to here, shapes. I betcha that’s what I did. I read it fast…Okay well I just remember thinking the same thing, that I wrote a lot more (words) the first time. I don’t think I listed anything besides shapes (on the post-test)…that’s when you say read the directions carefully.” Trixie did list one additional shape on her post-GV that was not listed on her pre-GV, trapezoid. Trixie’s interpretation of the increased score on her VHGT included a variety of factors such as “being back in school”, “being in math for a semester”, “I’m really good in math” and “maybe I’m just a good guesser.”

Summer’s score of a 7 on the VHGT and a 5 on the GV were the same on both the pre and post-tests. Summer had stated on the first journal prompt that she was “pretty comfortable” with geometric vocabulary. When asked about the Quick Draw and geometric vocabulary Summer replied, “Yeah, I really feel as though it (the Quick Draw) just helped with the spatial thinking.” Summer had listed the word trapezoid on her pre-GV although not on her post-GV and had listed the word rhombus on her post-GV although not on her pre-GV.

Piper's scores on both the GV and VHGT had increased, 3 to 5 and 1 to 10 respectively. With regard to her growth in identifying shapes, Piper explained how, "listening to everybody and different things that I started recognizing," had helped her add new vocabulary and begin to recognize shapes. Her identifying a kite and a rhombus on her post-GV that had not been on her pre-GV reflected these changes. Additionally, of the four interview participants, Piper had the most room for improvement with respect to the lower van Hiele levels as measured by the VHGT. The overarching theme linking the responses of the interviewee's who felt as though their geometric vocabulary had increased due to the *Quick Draw* activity was that of re-familiarization. At some point in their schooling they had come in contact with many of the shapes found in the *Quick Draw* activity, although they did not necessarily remember the names associated with these terms and shapes initially, but as the semester progressed they became re-acquainted with the vocabulary.

The *Quick Draw* Activity and Spatial Thinking

The Purdue Spatial Visualization Test (PSVT)

The PSVT (Guay, 1980) has three separate subtests, the Developments section (PSVT/DEV), the Rotations section (PSVT/ROT), and the Views section (PSVT/VIEWS) each measuring a different aspect of spatial ability. The scoring for each section of the PSVT consisted of a raw score between 0 and 12. Using SPSS, the descriptive statistics of sample size, mean, standard deviation, and

Table 10

Descriptive Statistics for the Purdue Spatial Visualization Test

	n	M		SD		Range	
		Pre	Post	Pre	Post	Pre	Post
PSVT/DEV							
Treatment	22	4.18	5.36	1.50	2.50	1-8	1-11
Control	15	4.87	5.20	2.50	2.76	1-9	1-10
PSVT/ROT							
Treatment	22	4.00	5.05	1.83	2.40	2-8	1-10
Control	15	5.40	5.53	2.35	2.45	1-12	1-12
PSVT/VIEW							
Treatment	22	5.27	4.91	2.16	3.02	2-8	0-12
Control	15	4.93	5.13	2.28	2.33	3-11	1-10

Note. PSVT = the Purdue Spatial Visualization Test, DEV = the Developments Section, ROT = the Rotations Section, and VIEW = the Views Section.

range were obtained (see Table 10). Additionally, 2 x 2 mixed design ANOVA's revealed that there were no significant differences in mean scores of the pre/post-PSVT/DEV, pre/post-PSVT/ROT, or pre/post-PSVT/VIEW with regard to the treatment and control groups (see Table 11). However, the effect-size, estimated omega squared, for the PSVT/DEV main effect of time (pre/post) had

Table 11

Purdue Spatial Visualization Test Analysis of Variance Results

Source	SS	df	MS	*F*	*p*	$\hat{\omega}^2$
PSVT/DEV	Between	subjects				
Group (G)	1.211	1	1.211	.162	.689	.000
Error	261.194	35	7.463			
	Within	subjects				
Time (T)	10.238	1	10.238	3.219	.081	.057
T X G	3.210	1	3.210	1.010	.322	.000
Error	111.303	35	3.180			
PSVT/ROT	Between	subjects				
Group (G)	15.894	1	15.894	2.068	.159	.028
Error	268.944	35	7.684			
	Within	subjects				
Time (T)	6.197	1	6.197	2.602	.116	.042
T X G	3.710	1	3.710	1.558	.220	.015
Error	83.344	35	2.381			
PSVT/VIEW	Between	subjects				
Group (G)	.059	1	.059	.007	.935	.000
Error	302.103	35	8.632			

Source	SS	df	MS	*F*	*p*	$\hat{\omega}^2$
PSVT/VIEW	Within	subjects				
Time (T)	.119	1	.119	.031	.862	.000
T X G	1.417	1	1.417	.363	.551	.000
Error	136.745	35	3.907			

Note. PSVT = the Purdue Spatial Visualization Test, DEV = the Developments Section, ROT = the Rotations Section, and VIEW = the Views Section, Time = pre-test, post-test, Group = treatment, control.

what was considered to be a medium effect-size ($\hat{\omega}^2$ = .0566), and the PSVT/ROT main effect of time (pre/post) had what was considered to be a small effect-size ($\hat{\omega}^2$ = .0415) as defined by Cohen's interpretation of effect-size (as cited in Keppel & Wickens, 2004). Keppel and Wickens (2004) point out, "Indeed, the type of effects that need careful research and statistical analysis are the medium and small ones" (p.162).

Written Responses and Journal Prompts

The twenty-four pre/post-Written Responses of the *Quick Draw* activity (see Appendix H) were analyzed to determine what influence, if any, the implementation of the Quick Draw activity had with respect to the spatial thinking of the participants. A pattern that emerged through analysis of the responses to the following Written Response questions:

"What did you see first?"

“What else do you see?”

was the idea of “dimension”, and whether the participants viewed the Quick Draw figure (see Table 11) in a one-, two-, or three-dimensional context . As noted earlier, the majority of participants (83%) reported seeing a triangle first. Then approximately 58% of the participants described the figure on the pre-Written Response in a one or two-dimensional context, and 42% described the figure in a three-dimensional context. The post-Written Responses revealed that 24% of the participants described the way they viewed the dimension of figure differently, with 16% changing their description from one or two-dimensional terminology to three-dimensional terminology and 8% changing their description from three-dimensional to one or two-dimensional terminology. For instance, Hannah responded to the pre-Written Response this way:

“What did you see first?” “The triangle.”

“What else do you see?” “Lines below the triangle.”

and to the post-Written Response as such:

“What did you see first?” “The triangle.”

“What else do you see?” “The cube.”

In the pre-Written Response, Hannah did not describe the figure as being three-dimensional as she did in the post-Written Response. Conversely, Kathryn responded to the pre-Written Response this way:

“What did you see first?” “The triangle.”

“What else do you see?” “It appears to be a cube with a corner chiseled out.”

and to the post-Written Response with a two-dimensional answer:

"What did you see first?" "The triangle."

"What else do you see?" "Two similar pentagons."

Kathryn's descriptions illustrate her viewing of the *Quick Draw* figure on the pre-Written Response as three-dimensional and then changing to a two-dimensional description on the post-Written Response. The transformations shown here in the participants' thinking on the pre- and post-written responses manifests itself in other areas apart from that of dimension.

Another aspect of the transformation of participants' thinking was illustrated through their responses to a question from the third journal prompt:

> "Do you feel your ability to see a variety of geometric figures embedded in the Quick Draw activities has increased throughout the semester? Please explain."

Twenty-six of the twenty-seven participants (96%) responded that they felt their ability to see a variety of geometric figures embedded in the *Quick Draw* activity had increased throughout the semester. In retrospect, it is duly noted that the question "Do you feel your ability to see a variety of geometric figures embedded in the Quick Draw activities has increases throughout the semester? Please explain." is ascertained to be a leading question. Of the three categories that emerged from their explanations, the majority of respondents referred to their ability to focus on the individual shapes as opposed to the whole picture as illustrated by Patty's response: "Yes, I am now breaking the shapes apart easier and not just seeing the whole." Additionally, Sandy points out, "Now I don't just see lines – I actually see the different shapes." A second category that surfaced was participants responding to how their "thinking had developed," as articulated by Paula: "Yes, you learn to look for them." A third category that was prevalent, connected the ability to see the embedded figures as a result of now knowing the names of the shapes, is demonstrated by Tisha's response, "Yes, because I have learned the names of them." One participant (4%) responded, "No, I feel like I see the most dominant (shape)." In addition to the repetition of the *Quick Draw* activity transforming participants' thinking with respect to awareness of dimension and embedded figures, how else, if at all, did this activity influence their spatial thinking?

The thirty participants were given the opportunity to explain how they accomplished the task of drawing the *Quick Draw* figure on the first journal prompt (see Appendix I) which was administered after eight of the eighteen *Quick Draws* had been completed. The prompt was,

> "What are your first thoughts when you are asked to draw geometric figures such as those in the Quick Draw activity? Please explain."

Two main categories emerged. The first category addressed participants' thoughts on "how they accomplished" the *Quick Draw* activity. The two main sub-categories that emerged were the words "remember" and "parts." Participants expressed that to be successful at completing the activity, they must be able to "remember" what the shape looks like and that this was a test of their memory. As Nora states, "I try to remember every line." The participants' other focus was specifically how they tried to remember the figure. The common response was that they would break the figure down into “parts” so that they could recreate it on their paper, as Mia explains, “My first thought is, how am I going to break up the parts of the picture so I can accurately place it on the paper?” It was not uncommon to find both of these themes combined into one response, as Tyler voices, “My first thought is to quickly try to get a mental photograph of the figure, then break it down into smaller figures.” The overarching concept that ties these categories of “remember,” and “mental photograph” together is that of spatial visualization and more specifically, spatial structuring which is defined as being the mental operation of constructing the form of an object through the organizing of the objects parts (Battista, 1999). Additionally, these statements correlate to Kosslyn’s (1994) conclusion that to form an image, perceptual wholes are built up from representations of parts and the interrelatedness of parts.

Aside from “how” the participants accomplished the *Quick Draw* activity, the second category that emerged through analysis of the first journal prompt was related to the participants’ “attitudes.” Participants classified the activity in three prominent ways: “challenging,” “frustrating,” and “fun.” Overall participants’ attitudes were positive with regard to their first thoughts about the *Quick Draw* activity, although there were two participants (7%) whose attitudes were dismissive as Di’s, “What does this have to do with anything?” Additionally, 17% of the participants’ responses from the first journal prompt were critical of their own drawing ability.

The last question posed on the Written Response gave participants an opportunity to voice their opinion on how they viewed their depictions or drawing representations of the *Quick Draw* image (see Table 12). The prompt asks:

> "How do you feel about your representation of the Quick Draw as compared to the actual Quick Draw?"

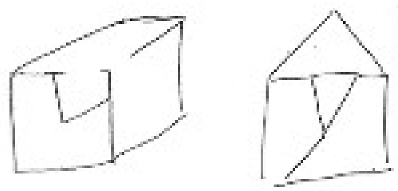
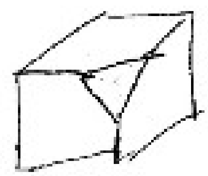
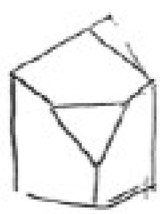
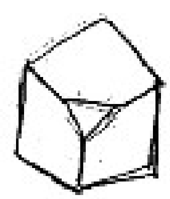
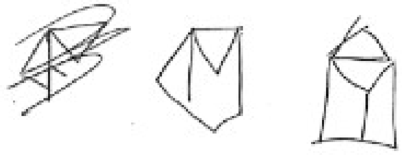
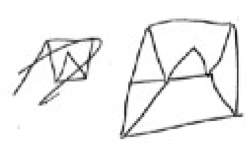
The most common responses were: "close," "okay," "similar," "not similar," and "general idea." Overall these comments were analogous on the pre- and post-Written Responses. These responses seem to be saying "I'm in the ballpark and that's acceptable for me."

Comparing the participant's pre- and post-drawing representations on the Written Responses, approximately 50% of the participants were judged, by the researcher, to have shown a notable improvement in their drawing representation of the *Quick Draw* figure as seen by Di's depictions shown in Table 12. The remaining 50% of the participants were judged, by the researcher, to have drawing representations that had not noticeably changed with approximately 21% of the drawing representations judged to be accurate on both the pre-Written Response and post-Written Response comparable to Cindy's depictions shown in Table 12. The remaining 29% of the drawing representations were judged, by the researcher, as being inaccurate representations on both the pre- and post-Written Responses as indicated by Lisa's depictions shown in Table 12. The participants had the chance to voice their feelings regarding their improvement or lack of improvement with respect to their drawing on the third journal prompt. Of the twenty-seven participants that responded to question two of the third journal prompt:

> "Do you feel your ability to draw geometric figures has improved

Table 12

A Comparison of Pre-Written Response Representations to Post-Written Response Representations

Actual Quick Draw Figure	Pre-Written Response Representation	Post-Written Response Representation
		
Di	 “very poor”	 “not bad, it came out nice”
Cindy	 “it’s pretty similar”	 “it’s pretty accurate”
Lisa	 “it’s definitely not the same”	 “it’s definitely off, I couldn’t reproduce it correctly”

throughout the semester? Please explain."

52% replied that their ability to draw geometric figures had improved throughout the semester, 26% responded "no," 11% said "somewhat," 7% said "a little," and 4% said "yes and no." The common theme between these responses was that the participants felt that their ability to draw the individual geometric shapes and/or the easier *Quick Draws* had improved, although they felt their ability had not improved on the more complicated *Quick Draws*. The overarching theme for the "no" responses equated to the respondents' beliefs that they just cannot draw. The theme that connected those that responded "yes" was their success to the change in the way they looked at the *Quick Draw* figures. Once again mentioning the figure as a whole and then "breaking" it into its parts. Also, Sue and Kathryn referred to the dimension of the figure in similar contexts. Kathryn states, "Seeing the (figure as) two dimensional as well as three dimensional helps (you to draw it)."

These results tend to suggest that many of the participants seemed to have benefited from participation in the *Quick Draw* activity in terms of being able to draw more accurate representations of geometric figures. The integrated experiences of seeing a variety of dimensions, and seeing the parts of the embedded figures were contributing factors in the development of their spatial representation skills. All in all, the activity improved how they organized, constructed, and described the geometric figures, training them to think more spatially. The participants tend to reinforce this idea as seen in their following responses to the third journal prompt.

Of the twenty-seven participants that responded to the first question on the third journal prompt:

> Do you feel your spatial thinking skills have improved throughout the semester? Please explain.

67% felt that their spatial thinking skills had improved throughout the semester, 7% responded that they thought their spatial thinking skills had improved “a little,” 11% were not sure, and 15% responded “no.” Of the participants that thought their spatial thinking skills had improved, 22% gave credit to the *Quick Draw* activity by name, 11% mentioned the manipulatives that were used in the Structures of Mathematics class, and 37% said that they just looked at the shapes differently. Paula’s response demonstrates this new perception: “I’ve learned to look for shapes in the quick draw, to be methodical about it.” Jesse, and one other participant commented similarly, “I now can see many more shapes inside the figures, but that really does not help me draw the figure.” This contradictory comment illustrates that for some participants there was disconnect between seeing and drawing the figures.

These results reveal that the majority of the participants perceived that their spatial thinking ability had improved throughout the course of the semester. In actuality, 45% of the participants in the treatment class saw an increase in their raw score on the PSVT. Looking at each individual subsection of the PSVT, 54% of the participants in the treatment class saw an increase in their raw score on the PSVT/DEV, 36% of the participants in the treatment class saw an increase in their raw score on the PSVT/ROT, and 27% of the participants in the treatment class saw an increase in their raw score on the PSVT/VIEWS.

Semi-Structured Post-Interviews

A topic of interest in the semi-structured post-interview was how the four interview participants viewed the influence of the *Quick Draw* activity with respect to their spatial thinking. Kathryn's pre/post scores on the PSVT were as follows; her PSVT/DEV increased from a 5 to a 9, her PSVT/ROT decreased from an 8 to a 7, and her PSVT/VIEWS decreased from an 8 to a 6. The influence the *Quick Draw* activity had on Kathryn's spatial thinking seemed to be intertwined with Kathryn's experiences with art. Kathryn was very focused on how her thinking changed from viewing the figures as three-dimensional to viewing them as two-dimensional, "It (the Quick Draw activity) allowed me to see differently. Um, you know, I see more three-dimensionally than normal but this allowed me to see two-dimensionally by pointing out that you can draw a triangle here, you can draw a parallelogram here…and then it helped me to draw it more accurately." For Kathryn, by exploring shape in two-dimension, she thought the *Quick Draw* activity "helped" her spatial thinking.

Trixie's pre/post scores on the PSVT/ROT and PSVT/VIEWS remained the same, 4 and 2 respectively, and her score on the PSVT/DEV increased from 3 to 4. During the semi-structured post-interview, Trixie made several references to the fact that she felt as though her "visualizing" had improved although her "drawing" had not improved, "I will say that I got better at visualizing. But I still can't draw…it's visualizing from my brain to my hand, I don't know what but there is some kind of disconnect still there.” During the semi-structured pre-interview Trixie had stated that with respect to the PSVT pre-tests (unaware of her scores) that she had thought the PSVT/ROT was the easiest type of spatial problem to manipulate and subsequently, this was the section of her highest pre-PSVT score. After seeing her post-PSVT scores her comment with regard to the PSVT/DEV was, “I would say that was probably the easier one for me to do because I could actually kind of visualize that (net) folding…” Overall, Trixie’s responses seem to suggest that there had been a transformation in her spatial thinking.

The results of Summer’s PSVT showed some inconsistencies. Her PSVT/DEV increased from a score of 1 to 4; her PSVT/ROT score of 3 remained the same on both the pre and post-test, and her PSVT/VIEWS score decreased from a 7 to a 0. In Summer’s response to the very first interview question regarding what she thought about the *Quick Draw* she stated, “I liked it. It definitely improved my spatial thinking. When I first started, I was like so overwhelmed even on the second look I couldn’t get it, and then the last few quick draws it was really easy to me.” This response might suggest the increase in Summer’s PSVT/DEV scores although results of her PSVT/VIEWS would seem to be inexplicable. In retrospect this information should have been made available to Summer during the semi-structured post-interview to gain her understanding of the PSVT/VIEWS results.

Piper’s pre/post scores on the PSVT/DEV of 3 and PSVT/ROT of 2 remained unchanged. Her PSVT/Views decreased by one point, from a 4 to a 3.

When asked what she thought about the *Quick Draw* activity, Piper responded, "I really enjoyed doing the quick draws. I was terrible at it at first but by the time we did the last one I was able to start recognizing more shapes and so I would draw the shapes that I knew for sure first and then try to go around." When asked specifically about spatial thinking she replied, "I think it helped me."

Overall, the treatment group's beliefs regarding the improvement of their spatial thinking skills, drawing skills, geometric vocabulary, and geometric shape recognition was assessed on the last question of the third journal prompt:

> "If you responded yes to any of the questions above, what might you attribute this improvement to? Why? Please explain."

The twenty-seven responses could be classified into three main categories, some participants listed more than one attribute. In the first category 43% of the participants attributed their improvement(s) to the "*Quick Draw*," and in the second category 15% attributed their improvement(s) to the "*Quick Draw* and discussion." The third category consisted of 48% of the participants who attributed their improvement(s) to "practice." Other responses included participants attributing their improvement(s) to their "competitive nature" and "manipulatives."

The *Quick Draw* Activity and Spatial Thinking Beliefs

The Spatial Thinking Attitude Survey (STAS)

The STAS (Hanlon, 2009) was a five point Likert type survey (see Appendix F) used to measure beliefs regarding spatial thinking and confidence

Table 13

Descriptive Statistics and Analysis of Variance Results for the Spatial Thinking Attitude Survey

Measure	n	M pre	M post	SD pre	SD post	Range pre	Range post
Treatment	29	57.61	55.89	6.91	8.87	38-67	32-69
Control	15	59.27	61.93	4.77	4.70	47-73	42-69

Source	SS	df	MS	*F*	*p*	$\hat{\omega}^2$
	Between	subjects				
Group (G)	289.556	1	289.556	3.655	.063	.058
Error	3247.700	41	79.212			
	Within	subjects				
Time (T)	4.430	1	4.430	.229	.635	.000
T X G	93.732	1	93.732	4.843	.033	.082
Error	793.524	41	19.354			

Note. Time = pre-test, post-test, Group = treatment, control.

regarding mentally picturing and drawing two and three-dimensional shapes. The possible range of scores was from 15 to 75. SPSS was used to obtain the descriptive statistics of sample size, mean, standard deviation, and range for the STAS. Also, a 2 x 2 mixed design ANOVA showed there to be no significant differences between mean scores on the STAS with regard to the treatment and control groups (see Table 13).

Semi-Structured Post-Interviews

An issue of interest in the semi-structured post-interview was what, if any, influence the *Quick Draw* activity had on the four interview participants' spatial thinking beliefs. When Kathryn was shown her pre/post STAS results she replied, "Yeah, I do think it (the Quick Draw) helped (change my beliefs) a lot." The trend that accounted for Kathryn's increased score on the STAS, from 61 to 67, was a result of the change in her selection of "agree" on the pre-test to "strongly agree" on the post-test for six of the ten questions regarding spatial thinking beliefs, specifically questions 2, 5, 6, 7, 9, and 10. These results suggest that Kathryn was a bit more passionate in her beliefs regarding spatial thinking at the end of the semester than she was at the beginning of the semester.

Trixie's score on the STAS remarkably decreased from 56 to 42. When the researcher, Adele, asked her to explain, the following conversation ensued:

Adele: The other thing I wanted to visit with you about was the attitude survey; that was this one. You were less positive the second time.

Trixie: I think that why that was is because I'm frustrated.

Adele: Okay, that was my question.

Trixie: It's frustrating when you are good at something and there's this really blatant weakness, which is what I consider it in my math. Because it's just there.

Adele: So what you're saying is when you took the pre-test you were optimistic?

Trixie: Well we hadn't done as much testing.

Adele: So you oh…

Trixie: I didn't realize how bad I was. I knew it was my weakness.

Adele: Right.

Trixie: But then you get in there and you start trying to do it.

Adele: Uh-huh.

Trixie: And it's very frustrating. It is.

Adele: I agree, I understand.

Trixie: When you're used to being able to do well when you're tested on most things, which I think I would say I am and then you really feel uncomfortable, it's very frustrating. And I think it's hard to stay focused when you get that frustrated.

During the second week of classes, when the pre-tests were administered the informed consents, selection of pseudonym, demographic survey, GV, and STAS were administered on Tuesday, and then the VHGT, and PSVT were administered on Thursday. So, Trixie had completed the pre-STAS before taking the pre-PSVT. Although Trixie already had a preconceived notion that spatial thinking was a "weakness", her frustration with the pre-PSVT came to light when she completed the post-STAS. Overall on the post-STAS she was much more insecure in her drawing ability and spatial ability (questions 11, 12, 13, and 15), although she did think that her ability to draw two-dimensional shapes had improved. With respect to questions 1 to 10 involving spatial thinking beliefs, Trixie's response values decreased on questions 1, 3, 7, 8, and 9, and increased in response to question 5:

"Spatial thinking skills are useful in other areas besides mathematics."

Trixie expressed that she felt as though, even with her "blatant weakness" in spatial thinking' she had still always been successful in mathematics along with all other endeavors apart from art. Overall, Trixie's beliefs regarding spatial thinking and confidence regarding mentally picturing and drawing three-dimensional shapes became less positive.

Summer's scores on the pre/post STAS increased by one point from 67 to 68, which was a result of her changing the score on question 12 from "neutral" to "disagree,"

"When I am asked to picture a three-dimensional object, I have a hard time."

When asked about her feelings regarding spatial thinking at the end of the semester as compared to how she felt at the beginning of the semester, Summer replied, "…it (the Quick Draw activity) was definitely easier, you know?"

Piper's scores on the pre/post STAS increased quite substantially, 57 to 66. When asked to comment on the increased score Piper answered, "I think it's just by doing those quick draws." Her responses to questions 1 through 8, and 10 regarding spatial thinking beliefs each increased although her response to the question "Manipulating shapes in my head is challenging" regarding spatial thinking ability decreased.

Overall, three of the four interview participants STAS scores increased from 61 to 67, 67 to 68, and 57 to 66. The treatment class, as a whole, had 54% 54% of participants show an increase in STAS scores, 43% of the participants STAS scores decreased, and 3% (one person) remained unchanged.

Pre-service Elementary Teacher's Views of Geometric and Spatial Thinking

Views Regarding Geometric Thinking

The first semi-structured pre-interview topic addressed the participants' previous experiences with geometry. All four participants were quick to recall their high school geometry class. The initial impression was that geometry was an isolated class with no connection to other experiences in their schooling. None of the participants made any negative connections with regard to their high school geometry class, although both Trixie and Summer did say that they were more comfortable with algebra. Also, Kathryn and Summer emphasized that they felt as though algebra was the true focus of high school mathematics.

When prompted about geometry experiences in middle school, Summer and Kathryn stated that they felt as though algebra was emphasized more than any other topic in mathematics at this level as shown by Kathryn's response, "It was a lot of the algebra, we have to get you through the algebra because that's what they want you to be able to do in high school." Trixie recalled doing geometry in middle school although she could not mention specifics of what geometry at this level encompassed. Piper could not remember doing any geometry in middle school.

When prompted about geometry experiences in elementary school both Kathryn's and Trixie's immediate response was with respect to "shapes." Initially, Summer and Piper had no recollection of geometry topics in elementary school until prompted with the word "shapes" at which time they both remembered learning about shapes. Additionally, Piper remembered working with pattern blocks and Kathryn with geoboards at this level of schooling although neither could remember the name of the manipulatives, which were ascertained through their descriptions.

Since many students equate the study of mathematics in general to only numbers, before delving into the participants views on geometric thinking, they were asked to comment on the phrase "mathematics is a language." Overall, Kathryn, Summer, and Trixie appeared to be agreeable to the statement "mathematics is a language," Summer's interpretation was, "I think it is, there are so many different languages and math is the same wherever you go, so it kind of is its own language, I guess…yeah it's easy to get lost if you can't understand the language." Kathryn responded by relating this observation, "Yes, my boyfriend for example, he's in elementary algebra so he cannot do algebra to save his soul so he fervently believes it's a language he doesn't understand." Trixie's observations were, "…math is a way of thinking…you have to know the language or maybe not just recognize it but actually know it…be able to speak it…because it's not scary if they know or learn it from early on." Piper agreed with the statement although she had no other comments with regard to mathematics as a language. Another aspect that emerged, as Trixie spoke about language, was her unexpected awareness as to why children in elementary school do not equate learning shapes as being synonymous with learning geometry, as seen by her comments, "Well because you don't think of it as geometry, you think of it as studying shapes…we were never told it was geometry…in third grade you say "oh, we're doing geometry," "oh, okay," and then you just build on it like you build on every other math."

The participants were now asked what they thought was meant by "geometric thinking." All four participants initial response made use of the word "shape." Piper replied, "Like shapes and stuff like that…how they are put together…like looking for patterns too." Summer and Kathryn both mentioned the term "3-D" (three-dimensional) as seen in Summer's remark: "Shapes are the first thing that come to mind, 3-D, and spatial thinking. Kathryn included "two-dimensional," along with "area" and "volume" in her description: "I would think geometric thinking involves shapes, involves three dimensional shapes, both two-dimensional and three-dimensional and then you have your equations to solve, how much volume and area, that type of thing for shapes but I'm not really sure what else." Trixie and Summer both included "spatial" to be a part of their description of geometric thinking, as Trixie states, "Well geometry is lots of things, like working with shapes, and spatial, that's what I think of mostly, say lines and that kind of thing." The overarching component with respect to geometric thinking seems to be "shape," although, apart from the concept of shape, geometric thinking appears to be difficult to describe as seen by the interview participants' portrayals of geometric thinking.

A common definition of geometric thinking for these participants could be compiled as such: geometric thinking involves the ability to think about and work with lines, two- and three-dimensional shape and space, and patterns, also, calculations involving volume and area. The last two aspects of volume and area typically fit into the study of measurement, which is usually integrated into coursework pertaining to geometry, and technically, geometry is translated as earth-measuring. One aspect of geometric thinking omitted from the participants' descriptions is that of properties and attributes of shape, which would directly relate back to geometric vocabulary.

Views Regarding Spatial Thinking

During the semi-structured pre-interview, the participants were asked about their thoughts regarding spatial thinking. Kathryn replied that she thought her spatial abilities were "okay" and that she was good not only with direction but also distance. When asked about drawing geometric shapes, Kathryn, whose pre-PSVT score was in the fourth quartile and whose mother is an artist, was very secure in her drawing ability. Kathryn seemed to have a very grounded understanding of spatial thinking, "shapes do take up space and you have to understand how much space something can take up." Additionally, Kathryn could see spatial thinking integrated into many "day to day things," along with shape, and space, she mentioned art, interior design, driving, direction, distance, playing with Lego's, and physics.

When asked about her thoughts regarding spatial thinking, Trixie replied, "I feel as though I am very lacking in it," and that she felt as though she was not a good judge of distance. Trixie's pre-PSVT score was in the first quartile. When asked about drawing, Trixie conveyed that drawing was "intimidating" to her. Trixie mentioned the rotations section of the PSVT to be the easiest for her and that was the section that she made the highest score on. As the problems in the Rotations section became more difficult, Trixie mentioned that she had trouble turning the object multiple times in her head. Trixie mentioned a few aspects of when spatial thinking might be used such as art, physics, and direction, along with playing sports. Additionally Trixie, on more than one occasion, mentioned gender differences in spatial ability, "I always think of guys as being kind of spatial; it's funny because of how they're raised and the things they do… I didn't play a lot of sports which is where I would guess boys get a lot of that spatial awareness, like from a baseball field." None of the other participants had made mention of gender differences, which might possibly be attributed to the differences in their age; Trixie was the only older, non-traditional student of the four interview participants.

When asked about her thoughts with respect to spatial thinking, Summer responded that spatial thinking was "hard" and that she, "can get lost anywhere!" Summer's pre-PSVT was in the first quartile. The most intriguing spatial account was that of Summer's. Summer disclosed that she had originally been an interior design major and after her first semester at college she changed her major because of her struggles with her interior design classes being so spatially driven, she stated, “I took all these interior design classes and it just was so hard for me to think of how rooms were this way and this way, it was so hard for me, I am so more into the color aspect of decorating.”

Piper had no response regarding spatial thinking until she was prompted to comment about the PSVT to which she replied, “That was difficult, the first one where it gave us an example, I really thought I understood that but then when I started going though the pages, my mind started to like kind of flip it one way and then I didn’t think it would work so I’d try to flip it the other way and I was like, I don’t know which way works…I think I am bad at it.” Piper continued to say that she had always been very good with direction, although with respect to drawing ability Piper replied, “I’m terrible at it.” Piper’s pre-PSVT score was in the first quartile. Interestingly enough, Piper thought the rotations section was the hardest section on the PSVT and that was the section she had made the lowest score on. When Piper was asked about other aspects of where you might use spatial thinking she replied, “Like on that test, so you know what you’re looking at.” Piper also emphasized, “I am not one to work stuff out in my head, even multiplication. I write it all out.”

Kathryn believed that spatial thinking activities should be integrated into the elementary grades, “I actually really do mostly because I was pushed for the algebra and I understand algebra more than a lot of people, but me wanting to be a well rounded person wants to know a lot more about more in math not just one side. I want the other side as well." Similarly Trixie states, "And I think it's just another part of your brain you're using…so I think it doesn't hurt to strengthen every part of your brain, so yeah I think it's important." Summer also agreed, "Yeah, if that was taught to me earlier (spatial thinking) then that class (interior design) wouldn't have been so hard." Pipers response regarding the importance of integrating spatial thinking at the elementary level was quite different, "It depends on what level I'm teaching. Like if I'm teaching at the lower levels probably not. But maybe as they get older teachers should start putting it into their lessons. Maybe not very much but maybe just a little bit. I think it really depends on what age group you're teaching."

The participants seem to each have their own unique understanding of spatial thinking as it applies directly to their lives. Albeit, the general consensus is that spatial thinking is hard.

Conclusion

This embedded quasi-experimental mixed methods study investigated the influential nature of an activity called *Quick Draw* with respect to pre-service elementary, early childhood, and special education teachers' beliefs regarding spatial thinking, their spatial ability, and their geometric thinking. Additionally, this study also explored how pre-service teachers view their general awareness of spatial and geometric thinking.

Both quantitative and qualitative data was analyzed to examine the influence of the *Quick Draw* activity on pre-service elementary teachers' geometric thinking. The results of the quantitative analysis showed there to be no significant differences in pre/post mean scores on the Van Hiele Geometry Test or the Geometric Vocabulary test with respect to the treatment or control groups. Analysis of the qualitative data revealed that the pre-service teachers appear to be much more comfortable with geometric shape as opposed to geometric terms involving attributes and properties of shape. The majority of the pre-service teachers believed their geometric vocabulary did improve throughout the semester by means of the “discussion” that ensued from the *Quick Draw* activity and also through the “familiarity” aspect of seeing the *Quick Draw* figures. This idea was reinforced through further quantitative analysis that showed there was a significant increase in the use of the word “rhombus” on the Geometric Vocabulary test, for the treatment group.

To investigate the influence of the *Quick Draw* activity on pre-service elementary teachers’ spatial thinking, both quantitative and qualitative data was analyzed. The quantitative results showed there to be no significant differences in mean scores on the PSVT with regard to the treatment and control groups. The qualitative analysis revealed that the majority of pre-service teachers felt as though their ability to see the embedded figures in the *Quick Draw* activity improved throughout the semester. This, in turn, they attributed to improving their ability to do the *Quick Draw* activity and ultimately led to a perceived improvement of their spatial thinking ability. Further analysis revealed that the pre-service teachers believed their thinking, with respect to the *Quick Draw* activity, had changed throughout the semester. They began to focus on the parts of the *Quick Draw* figure as opposed to only seeing the shape as a whole. Their idea of dimension expanded as those who originally saw the figures as only one or two-dimensional shapes could now see the figure as being three-dimensional. Additionally, there were those pre-service teachers who originally saw certain figures as only being three-dimensional who could now see the figure two-dimensionally. Moreover, some pre-service elementary teachers felt that being able to recognize the names of the shapes helped them to recall how to draw the shape from memory. The integrated experiences of seeing a variety of dimensions, and seeing the parts of the embedded figures contributed to the development of their spatial representation skills, thus improving how they organize, construct, and describe the geometric figures, training them to think more spatially. Furthermore, the majority of the pre-service elementary teachers also felt as though their drawing representations of the *Quick Draw* figures did improve throughout the semester.

Together, quantitative and qualitative data was analyzed to explore the influence of the *Quick Draw* activity on pre-service elementary teachers' spatial thinking beliefs and confidence regarding mentally picturing and drawing two and three-dimensional shapes. There were no significant differences found between mean scores on the STAS with regard to the treatment or control groups.

The fifth question on the third journal prompt summed up the pre-service teachers' beliefs regarding the improvement of their spatial-thinking skills, drawing skills, geometric vocabulary, and geometric shape recognition. On this prompt they were asked to determine what attribute would account for their improvement in any of the aforementioned topics. The responses all fell into five categories: the “Quick Draw,” the “Quick Draw and discussion,” “practice,” “manipulatives,” and “competitive nature”.

The analysis of the qualitative semi-structured interview data suggests suggests that these pre-service elementary teachers’ views regarding geometric thinking were immediately and initially connected to the idea of shape. Also, they tended to feel as though they were not comfortable with geometric vocabulary. This could possibly have been a result of the emphasis that they felt was put on algebra throughout their schooling. The more comfortable the pre-service elementary teachers seemed to be with their own spatial ability, the more applications they tended to see in aspects of spatial thinking. Additionally, the more aware the pre-service elementary teachers were of their own spatial thinking, combined with general awareness of spatial thinking overall, the more emphasis they believed should be placed on the integration of spatial thinking into the elementary curriculum.

In Chapter V, a summation of the findings along with conclusions will be offered. Chapter V will also present a discussion of the consequences of the results with respect to implications regarding teacher education, along with future directions for research in the area of spatial and geometric thinking.

CHAPTER V

SUMMARY, CONCLUSIONS, and RECOMMENDATIONS

Spatial thinking not only manifests itself in many aspects of daily life, but it is also a skill that is essential for success in STEM fields from which scientific discoveries and progress are made (National Research Council, 2006). The importance of spatial thinking with regard to mathematics is emphasized in every aspect in the National Council of Teachers of Mathematics (NCTM, 2000) geometry standards for instructional programs in pre-kindergarten through twelfth grade. Additionally the National Research Council points out that not only is spatial thinking a learnable skill, but that it is a skill that should be matriculated throughout the entire educational system. Taking into consideration that teachers tend to teach mathematics in the manner that they have been taught mathematics (Sundberg & Goodman, 2005), and that teachers who are more confident in their own spatial abilities are more likely to incorporate spatial thinking into learning situations in their own classrooms (Battista 1990), teacher education programs throughout the country have the opportunity to impact future teachers' spatial skills. This could lead to improved instructional activities involving spatial skills in the K-12 classroom. For the integration of spatial thinking to become an area accentuated at the elementary school level, pre-service elementary teachers should have an understanding of spatial thinking, develop confidence in their own spatial thinking ability, and be able to use pedagogical strategies that develop spatial thinking skills in their own students.

This embedded quasi-experimental mixed methods study was designed to investigate the influence of *Quick Draw* activities on pre-service elementary teachers geometric thinking, spatial thinking, and beliefs regarding spatial thinking. Additionally, this study delved into how pre-service teachers view their general awareness of spatial and geometric thinking. The research questions guiding the study were:

- Does the integration of *Quick Draw* activities into a mathematics content course result in significant differences in mean scores on the Van Hiele Geometry Test, the Geometric Vocabulary test, the Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey for pre-service elementary teachers?
- How does the integration of *Quick Draw* activities into a mathematics content course influence pre-service elementary teachers' geometric thinking, spatial thinking, and spatial thinking beliefs?
- How do pre-service elementary teachers view their own understanding of spatial thinking and geometric thinking?

The sixty participants involved in this study were primarily Caucasian, female pre-service elementary teachers. At the onset of the study there were thirty participants in each of the treatment and control groups. Both quantitative and qualitative data was collected from the treatment group, while only quantitative data was collected from the control group. Both the treatment and control groups completed an informed consent, demographic survey, pre/post Van Hiele Geometry Test (VHGT), pre/post Geometric Vocabulary Test (GV), pre/post Purdue Spatial Visualization Test (PSVT), and the pre/post Spatial Thinking Attitude Survey (STAS). Additionally, the treatment group completed pre/post Written Responses of a *Quick Draw* activity and three Journal Prompts. Semi-structured interviews were also conducted with four participants from the treatment group who were purposively chosen to represent different levels of spatial and geometric thinking. Results from the quantitative data was used to determine if the integration of the *Quick Draw* activities resulted in significant differences in mean scores on the VHGT, GV, PSVT, and the STAS. Analysis of the qualitative data, the written responses, journal prompts, and semi-structured interviews was used to examine the influence of the *Quick Draw* activities on pre-service elementary teachers spatial and geometric thinking along with their spatial thinking beliefs. Moreover, the qualitative data was also utilized to ascertain how pre-service elementary teachers viewed their own understanding of geometric and spatial thinking.

Quick Draw and Geometric Thinking

The combination of the first two research questions investigated the influence of the *Quick Draw* activity on pre-service elementary teachers' geometric thinking. Both quantitative and qualitative data was collected and analyzed. With respect to the quantitative analyses, descriptive statistics such as sample size, mean, standard deviation and range were determined for data obtained from the Van Hiele Geometry Test (VHGT), two subsets of the VHGT called the VHGT<7 in which only participants who had scored less than 7 on the VHGT were analyzed, the VHGT > 7, and the Geometric Vocabulary test (GV). Additionally, the VHGT, VHGT<7, and VHGT > 7 were analyzed using 2 x 2 mixed design ANOVA's and the GV was analyzed using a 2 x 2 randomized block design ANOVA. The results of the quantitative analyses revealed no significant differences in pre/post mean scores on the VHGT, VHGT > 7, and the GV with respect to the treatment or control groups. This suggests that there was no significant change in either group's geometric thinking with respect to geometric vocabulary, VHGT score, or VHGT score greater than 7. However, there was a significant difference in mean scores of the VHGT < 7 for the main effect of time ($F = 6.884$, $p = .015$). These results suggest that both the treatment group ($M_{pre} = 2.36, M_{post} = 5.79$) and the control group ($M_{pre} = 1.82, M_{post} = 3.73$) mean pre-test score of VHGT less than 7 increased significantly.

Analysis of the qualitative data (i.e. written responses, journal prompts, and semi-structured interviews) revealed that pre-service elementary teachers appear to be more comfortable with the concept of geometric shape as opposed to that of geometric terms involving attributes and properties of shape. In addition, analysis of field notes of discussions during the *Quick Draw* activities also revealed that the class-driven dialogues did indeed focus primarily on geometric shape. One outcome, which came about as a result of the qualitative analysis of the GV was the pre-service elementary teacher's use of the words "diamond" and "rhombus." Diamond was commonly found as a response on the GV, and although it is not considered to be incorrect geometric vocabulary it is anticipated that pre-service elementary teachers ideally should be able to identify this shape as a rhombus. This correlates to Chang's (1992) research when he determined that pre-service teachers struggle with understanding and communicating the mathematical language associated with geometric thinking.

Based on the results obtained from qualitative analysis, the use of the words "diamond" and "rhombus" were further analyzed quantitatively for both the treatment and control groups using a McNemar statistical test. The results showed that although there were no significant differences in the use of the word "diamond" between the pre- and post-GV with regard to the control or treatment groups, there was a significant increase in the proportions of usage ($S = 9.0000$, $p = .0054$) in the use of the word "rhombus" from the pre-GV (46.43%) to the post-GV (78.57%) with regard to the treatment group. There were no significant differences found with respect to the use of the word "rhombus" on the pre/post-GV for the control group. This suggests that the *Quick Draw* activity may in fact have helped to enhance the pre-service elementary teachers' geometric vocabulary by introducing or re-familiarizing them with the geometric vocabulary term of rhombus, reinforcing Vygotsky's (1986) concept of the Zone of Proximal Development (ZPD). In this context, the geometric ZPD would be the area created through the *Quick Draw* activity of drawing and discussion in which the spontaneous concept, "diamond" for instance, meets its counterpart, the scientific concept “rhombus.” Moreover, other research has indicated that the Quick Draw activity has had a positive impact on geometric vocabulary (Richardson & Stein, 2008; Bentley, 1999).

Additional qualitative analysis revealed that the majority of the pre-service elementary teachers believed their geometric vocabulary did improve throughout the semester. The two influential factors that emerged through analysis of their explanations of this phenomenon were that of the “discussions” that ensued from the *Quick Draw* activity and the increased “familiarity” of seeing certain geometric shapes in the *Quick Draw* figures. In actuality, 46% of the participants’ in the treatment class scores on the GV did increase, and 56% of participants who initially scored less than 7 on the VHGT (a score indicative of placing a participant in the lower three van Hiele levels) also saw an increase in their VHGT score.

Quick Draw and Spatial Thinking

The combination of the first two research questions explored the influence the *Quick Draw* activity had on pre-service elementary teachers spatial thinking. Both quantitative and qualitative data was collected and analyzed. With respect to the quantitative analyses, descriptive statistics such as sample size, mean, standard deviation and range were determined from the data obtained for each of the subsections of the Purdue Spatial Visualization Test (PSVT) for the control and treatment groups. The Developments section (PSVT/DEV), Rotations section (PSVT/ROT) and Views section (PSVT/VIEWS) were analyzed using

2 x 2 mixed design ANOVA's. The results of all quantitative analyses showed there to be no significant differences in pre/post mean scores on the PSVT/DEV with respect to the treatment or control groups.

The analysis of the qualitative data, written responses, journal prompts, and semi-structured interviews, resulted in multi-faceted aspects emerging with respect to the influence of the *Quick Draw* activity on pre-service elementary teachers spatial thinking. The qualitative analysis revealed that the majority of pre-service elementary teachers felt as though their ability to see the embedded figures in the *Quick Draw* activity improved throughout the semester, which in turn improved their ability to do the *Quick Draw* activity, which they then in turn attributed to an improvement in their spatial thinking ability. In other words, the pre-service elementary teachers believed their spatial thinking ability had improved based on the premise that their ability to see and draw the *Quick Draw* figures had improved.

Furthermore, the analysis revealed that the pre-service teachers believed these consequences were a result of a change in their "thinking" over the course of the semester with respect to how they completed the *Quick Draw* activity. Three themes emerged to account for the change in their "thinking." First, the pre-service elementary teachers related that they began to focus on the "parts" of the *Quick Draw* figure as opposed to only seeing the shape as a whole. This not only parallels Kosslyn's (1994) conclusion that to form an image, perceptual wholes are built up from the representations of the parts of the figure and the interrelatedness of these parts, but this part to whole relationship is also seen in the hermeneutic circle (Byrne, 1998). In this context the participant's understanding of the vocabulary associated with the geometric shape as a whole is established by their understanding the vocabulary of each of the individual geometric shape parts, properties, or attributes. Second, their idea of "dimension" expanded; those who originally saw certain *Quick Draw* figures as a montage of one-dimensional lines and two-dimensional shapes could now see the figures as being three-dimensional. Additionally, there were those pre-service elementary teachers who originally saw certain *Quick Draw* figures as only being three-dimensional who could now see the figure two-dimensionally. Third, the pre-service elementary teachers felt as though being able to "recognize the names of the shapes" through means of the class discussions helped them recall how to draw the shape from memory. The integrated experiences of seeing a variety of dimensions, and seeing the parts of the embedded figures contributed to the development of their spatial representation skills, thus improving how they organize, construct, and describe the geometric figures, training them to think more spatially. Furthermore, the visual connection forged between the geometric shapes and their names is another example of Vygotsky's (1986) concept of the Zone of Proximal Development (ZPD) in a geometric context.

Another facet of the influence of the *Quick Draw* activity with respect to spatial thinking was that the majority of the pre-service elementary teachers felt as though their drawing representations of the *Quick Draw* figures did improve throughout the semester. One explanation for this was that they felt that being able to see some of the figures in both a two-dimensional form and a three-dimensional form assisted them in recreating the image.

The compilation of these outcomes would seem to infer that the *Quick Draw* activity had a positive influence on the spatial structuring skills of the pre-service elementary teachers. This corroborates other research indicating targeted instructional practices can impact spatial thinking ability (Guven & Kosa, 2008; Yackel & Wheatley, 1990).

Quick Draw and Spatial Thinking Beliefs

In addition to examining the influence the *Quick Draw* activity had on pre-service elementary teachers' spatial abilities, the study explored the impact of the *Quick Draw* activity on the spatial thinking beliefs and confidence regarding the ability to mentally picture and draw two- and three-dimensional shapes. Both quantitative and qualitative data was collected and analyzed. With respect to the quantitative analyses, descriptive statistics such as sample size, mean, standard deviation and range were determined for the data obtained from the Spatial Thinking Attitude Survey (STAS). Additionally, the STAS was analyzed using a 2 x 2 mixed design ANOVA. The results showed there to be no significant differences in pre/post mean scores on the STAS with respect to the treatment or control groups.

Looking at percentages of increases and decreases on raw scores of the STAS for the treatment class revealed these scores to be closely matched with approximately just as many pre-service elementary teacher's raw STAS scores increasing as decreasing. The increased percentages would infer a positive shift in disposition from the beginning of the semester to the end of the semester, with respect to spatial thinking beliefs and confidence regarding mentally picturing and drawing two- and three-dimensional shapes. The decreased percentages would infer a negative shift in disposition from the beginning of the semester to the end of the semester, with respect to spatial thinking beliefs and confidence regarding mentally picturing and drawing two- and three-dimensional shapes. One account of the decrease in positive affect is explained by Trixie's (first quartile in spatial thinking, fourth quartile in geometric thinking) comments regarding her spatial thinking skills, which surfaced during a semi-structured post-interview, "I didn't realize how bad I was… I knew it was my weakness. But then you get in there and you start trying to do it. And it's very frustrating. It is." Trixie had taken the pre-STAS (score of 56) before she had taken the pre-PSVT and consequently her post-STAS (score of 42) reflected her frustration with the challenging PSVT. This trend of overestimating one's below average ability can be corroborated through Kruger and Dunning's (1999) research in which they determined that their participants who scored in the bottom quartile on tests of logic, grammar, and humor significantly overestimated their ability with how they would perform on tests in the aforementioned areas.

Analysis of the final journal prompt summed up the pre-service elementary teachers' beliefs regarding the overall influence of the *Quick Draw* activity with respect to the improvement of their spatial thinking skills, and drawing skills along with geometric vocabulary, and geometric shape recognition. On this prompt they were asked to determine what attribute would account for their improvement in any of the aforementioned topics. The responses all fell into five categories first, most commonly mentioned was the “Quick Draw”, second, the “Quick Draw and discussion”, third, “practice”, fourth, “manipulatives” and fifth, one pre-service elementary teacher responded, “my competitive nature”. The response regarding manipulatives might possibly be accounted for by the introduction of some manipulatives, such as base-10 blocks, multi-base pieces, fraction circles, and Cuisenaire rods, into the Structures of Mathematics class perhaps making a considerable impression on some participants who have never had the opportunity to learn in a “hands on” atmosphere. This directly correlates to Bruner’s Constructivist theory in that learning is an active process and that new knowledge is constructed based on previous or current knowledge (Bruner, 1966). The physical, concreteness of the manipulatives aids in promoting understanding of a concept while additionally embeds a spatial representation into the learning of the concept.

Geometric and Spatial Thinking Awareness

The third research question explored pre-service elementary teachers’ views on their own understanding of spatial thinking and geometric thinking. This was accomplished through semi-structured pre-interviews, which were analyzed using constant comparative method analysis (Strauss & Corbin, 1998). The analysis of this data suggests that the pre-service elementary teachers’ views regarding geometric thinking are immediately and initially connected to the idea of shape as studied in elementary school. Also, they tend to feel as though they are not comfortable with geometric vocabulary. This could possibly have been a result of the emphasis that they feel was put on algebra throughout their schooling, as Kathryn relates, “It was a lot of the algebra, we have to get you through the algebra because that’s what they want you to be able to do in high school.”

The analysis of the semi-structured pre-interviews with respect to views on spatial thinking suggests that the more comfortable pre-service elementary teachers seem to be with their own spatial ability, the more applications they tend to see in aspects of spatial thinking. Additionally, the more aware pre-service elementary teachers are not only of their own spatial thinking, but also of spatial thinking in general, the more emphasis they believe should be placed on the integration of spatial thinking into the elementary curriculum.

Implications for Teacher Education Programs

Results of this study have implications for elementary pre-service teacher education. Ultimately, responsibility falls upon the teacher education programs to be modified to prepare future educators to meet the needs of their future students. Since the teacher is such an integral part of student learning, for students to reach their potential in the areas of geometric and spatial thinking, the teachers must be comfortable and confident in their own abilities in these areas.

With respect to geometric thinking, pre-service elementary teachers need to be comfortable not only with the identification of geometric shapes but also with the geometric vocabulary associated with the properties and attributes of these shapes. If the goal is for elementary students to have had the appropriate geometry experiences so that they have developmentally passed through the first three van Hiele levels, recognition, analysis, and relationships, so as to prepare them so they may be successful in high school geometry, then it is imperative that their teachers have mastered these van Hiele levels as well. The *Quick Draw* activities not only have the potential to initiate this dialog with pre-service elementary teachers, but also if their enjoyment of the activity is memorable, then there is a strong likelihood that they will present this activity in their own classrooms. In turn, this instructional strategy has the propensity to enhance their student's geometric thinking.

With respect to spatial thinking, there needs to be a heightened awareness among pre-service elementary teachers. Spatial thinking is emphasized in every aspect of the NCTM Geometry Standards Pre-K through 12 (NCTM 2000) and yet pre-service elementary teachers struggle with their understanding, ability, and confidence relating to spatial thinking. Since pre-service elementary teachers being predominately female, may tend to benefit from spatial development training more than males (Fennema & Tartre, 1985; Friedman, 1995), then the *Quick Draw* activities appear to be promising, not only to start the conversation to promote understanding of spatial thinking, but also to aid in increasing confidence in spatial structuring skills and drawing ability. As stated previously, if as students, these pre-service elementary teachers enjoy the *Quick Draw* activity, and they present this activity in their own classrooms, this instructional strategy has the propensity develop their student's spatial structuring skills.

Recommendations for Future Research

Future research in the areas of spatial and geometric thinking with respect to pre-service teachers is called for to bring about the necessary updating of teacher education programs. Suggested possible investigations as a consequence to this study are:

1) This study could be repeated with more careful consideration given to the focus of the Quick Draw activity class discussions, emphasizing properties and attributes of shapes and to the names of the shapes.
2) Longitudinal studies could be conducted following the participants through Foundations of Geometry and Measurements and then through their methods courses to explore how their spatial and geometric thinking has or has not evolved.
3) Disclosed in this study were discrepancies between the quantitative and qualitative results. This opens the door for further mixed methods research in the area of exploring the influence of the *Quick Draw* activity on pre-service elementary teacher's geometric and spatial thinking.
4) With further exploration of the influence of the *Quick Draw* activity on geometric and spatial thinking, there is a need to develop a reliable instrument that measures geometric thinking with emphasis on the first

three van Hiele levels related to the *Quick Draw* activity, recognition, analysis, and relationships.

Concluding Comments

The majority of the pre-service elementary teachers who participated in this study had not taken the Foundations of Geometry and Measurement class that is part of the required coursework for their major. Although many of these pre-service elementary teachers appeared to be weak in the area of geometric thinking, the Foundations of Geometry and Measurement class along with their mathematics methods classes would, in an ideal world, allow them the experiences to be accomplished in the lower three van Hiele levels of geometric thinking. Apart from the spatial thinking skills that are concurrently developed with geometric thinking through the elementary pre-service teachers' interaction with shape and space in the Foundations of Geometry and Measurement class, there is no added emphasis placed on awareness of spatial thinking or spatial ability in this course.

With this being said, the role of research concentrating on pre-service teachers' awareness of spatial thinking and spatial ability needs to be a major focus to be a leading force in the reform in mathematics education. This becomes a circular argument starting with the fact that there is currently a shortage of science, technology, engineering, and mathematics (STEM) majors and that this shortage is anticipated to become more exacerbated in the future (Jackson, 2002; Friedman, 2005). Therefore, we need more undergraduate students to major in STEM fields and these fields are very spatially driven, so in turn we need to allow K-12 students to experience an assortment of spatial thinking activities that develop a variety of spatial abilities. To do this we must first start by initiating a general awareness of spatial thinking and spatial ability in all pre-service teachers as a part of their undergraduate curriculum.

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APPENDICES

APPENDIX A

IRB APPROVALS

UNIVERSITY OF CENTRAL OKLAHOMA

Office of Research & Grants
Academic Affairs

June 24, 2009

Professor Adele Hanlon
Dr. Juliana Utley
Department of Mathematics
College of Mathematics and Sciences
Campus Box 171
University of Central Oklahoma
Edmond, OK, 73034

Dear Adele and Juliana:

Re: Application for IRB Review of Research Involving Human Subjects

We have received and reviewed your revised application (UCO IRB# 09084) entitled, Investigating the Influence of an Activity Called "Quick Draw" on Pre-Service Teachers Spatial and Geometric Thinking, and find all stipulations in order. The UCO Institutional Review Board is pleased to inform you that your IRB application has been approved. An approved, stamped Informed Consent Form will be sent to you by campus mail.

This project is approved for a one year period but please note that any modification to the procedures and/or consent form must be approved prior to its incorporation into the study. A written request is needed to initiate the amendment process. You will be notified in writing prior to the expiration of this approval to determine if a continuing review is needed.

On behalf of the Office of Research & Grants and UCO IRB, I wish you the best of luck with your research project. If our office can be of any further assistance in your pursuit of research, creative & scholarly activities, please do not hesitate to contact us.

Sincerely,

G. Willis by LA

Geoff Willis Ph.D.
Professor of Operations Management
College of Business
University of Central Oklahoma
405-974-5345
GW/LA

Oklahoma State University Institutional Review Board

Date:	Wednesday, June 24, 2009
IRB Application No	ED0985
Proposal Title:	Investigating the Influence of an Activity Called "Quick Draw" on Pre-Service Teachers Spatial and Geometric Thinking
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 6/23/2010

Principal Investigator(s):

Adele E Hanlon	Juliana Utley
4025 Tamarac Ct.	245 Willard
Edmond, OK 73003	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 219 Cordell North (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Shelia Kennison, Chair
Institutional Review Board

APPENDIX B

DEMOGRAPHIC SURVEY

ID______________________________ **Date** ______________________

Demographic Information

Gender: M or F (circle one) **Age**: ___________ years

Ethnicity: _____ African-American _____ Asian _____Caucasian

_____ Latino _____ Native-American

_____ Other (please specify: ___________________________)

Major: ____________________________

Classification: Freshman Sophomore Junior Senior
(circle one)

Did you take a geometry course in high school? Yes No
(circle one)

If yes, what was your grade in this class? __________

Have you already taken Foundations of Geometry and Measurement? Yes No (circle one)

If yes, what was your grade in this class? ___________

Are you currently taking Foundations of Geometry and Measurement this semester? Yes No (circle one)

What toys did you play with as a child?

What was your favorite toy?

What video games did/do you play?

What was you favorite video game?

What computer games did/do you play?

What was your favorite computer game?

APPENDIX C

PURDUE SPATIAL VISUALIZATION TEST

(PSVT)

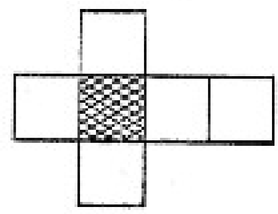
EXAMPLE QUESTIONS FROM THE DEVELOPMENTS SECTION, ROTATIONS SECTION, AND THE VIEWS SECTION

Do NOT make any marks in this booklet.
Mark your answers on the separate answer card.

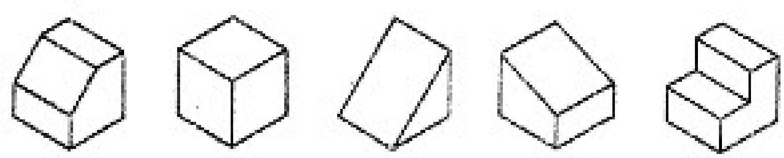
SECTION 1: DEVELOPMENTS

Directions

The first section of this test consists of 12 questions designed to see how well you can visualize the folding of developments into three-dimensional objects. Shown below is an example of the type of question included in the first section of this test.



A B C D E



Presented is a development and five three-dimensional objects. The development shows the inside surfaces of a three-dimensional object. The shaded portion of the development indicates the bottom surface of the three-dimensional object. You are to:

1. picture in your mind what the development looks like when folded into a three-dimensional object;
2. select from among the five objects (A, B, C, D, or E) the one that looks like the folded development.

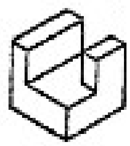
What is the correct answer to the example shown above?

Do NOT make any marks in this booklet.
Mark your answers on the separate answer card.

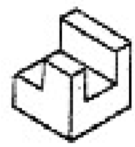
SECTION 2: ROTATIONS

Directions

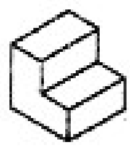
The second section consists of 12 questions designed to see how well you can visualize the rotation of three-dimensional objects. Shown below is an example of the type of question included in the second section.



IS ROTATED TO

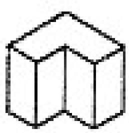


AS

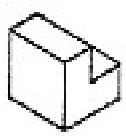


IS ROTATED TO

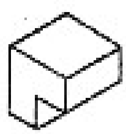
A



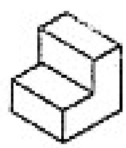
B



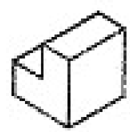
C



D



E



You are to:

1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

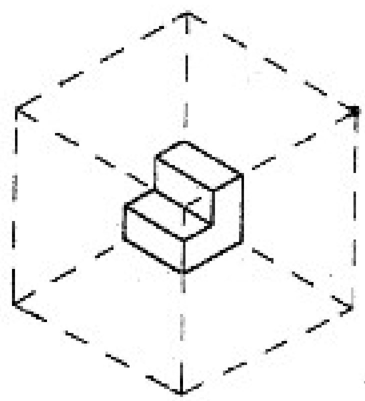
What is the correct answer to the example shown above?

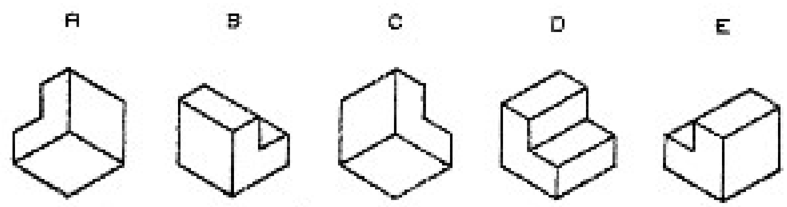
Do NOT make any marks in this booklet.
Mark your answers on the separate answer card.

SECTION 3: VIEWS

Directions

The third section consists of 12 questions designed to see how well you can visualize what three-dimensional objects look like from various viewing positions. Shown below is an example of the type of question included in the third section.





The example shows an object positioned in the middle of a "glass box" and five drawings representing what the same object looks like when seen from different viewing positions. The black dot in the top right corner of the "glass box" identifies the desired viewing position. You are to:

1. imagine yourself moving around the "glass box" until the black dot is located directly between you and the object;

APPENDIX D

INSTRUMENT USE APPROVALS

From: gmbodner@purdue.edu
Subject: **Re: PVRT**
Date: March 19, 2009 1:27:43 PM CDT
To: adele hanlon adelehanlon@sbcglobal.net

It is available from me for free and the 26th of March and you have my permission to make as many copies as you need.

Quoting Adele Hanlon <adelehanlon@sbcglobal.net>:

Hi Dr. Bodner,
Thank you for responding, I did however track your test down as it is available through ETS for $25! I am not sure of the protocol associated with using your test and just to be on the safe side I am requesting your permission to make use of the PSVT as a measure of spatial thinking for my dissertation. I will need to make 140 copies of the PSVT, and this project is not funded.
Thank you again for your time,
Adele

On Mar 19, 2009, at 1:08 PM, gmbodner@purdue.edu wrote:

I will be on the road until March 26th. At that time I will send you a copy.

Quoting Adele Hanlon <adelehanlon@sbcglobal.net>:

Hi Dr. Bodner,
My name is Adele Hanlon and I am currently working on my doctorate at Oklahoma State University in Professional Education Studies with an emphasis in mathematics education. I am to the point where I am focusing on my dissertation and I am interested in studying preservice elementary teachers spatial thinking, and geometric thinking. I was hoping to get permission to use your Purdue Visualization of Rotation Test as a pre, post measure. I had read that the complete test consists of three different areas although I have not been able to locate the complete test, I was also hoping you might lead me in the right direction as to where this might be found.
Thanks so much for your time,

Adele

Re: Van Hiele Geometry Test
Zalman Usiskin [z-usiskin@uchicago.edu]
Sent: Tuesday, June 23, 2009 5:14 PM
To: Adele Hanlon
Dear Adele:

You have our permission to copy and use the Van Hiele Geometry Test in the dissertation study you have described.

We would appreciate receiving a copy of your dissertation or any other publication of the results you find using the test.

Your interest in this work is appreciated.

Best wishes for success in your work.

Zalman Usiskin
Professor Emeritus of Education
Director, University of Chicago School Mathematics Project
The University of Chicago
6030 S. Ellis Avenue
Chicago, IL 60637

Adele Hanlon wrote:
> Hi Dr. Usiskin,
>
> I am currently a doctoral student at Oklahoma State University. I am writing to request the use of the "Van Hiele Geometry Test" in two of my classes, Fall semester, 2009. I am currently working on my dissertation in which the focus is introducing an activity into my pre-service teachers curriculum and ascertaining if this activity will increase their spatial ability along with their level of geometric thinking. The Van Hiele test will be given to approximately 70 students as a pre/post measure of geometric thinking. I assure you that "Copyright 1980 by the University of Chicago. Reprinted with permission of University of Chicago" will appear on each copy of the test and I will be glad to update you with a copy of the results attained through use of this instrument.
>
> Thank you for your time,
>
> Adele Hanlon
> University of Central Oklahoma
> Department of Mathematics and Statistics
> 100 N. University Dr.

> Box 129
> Edmond, OK 73034
> **Bronze+Blue=Green** The University of Central Oklahoma is Bronze,
> Blue, and Green! Please print this e-mail only if absolutely
> necessary!
>
> **CONFIDENTIALITY** -This e-mail (including any attachments) may
> contain confidential, proprietary and privileged information. Any
> unauthorized disclosure or use of this information is prohibited.
>

APPENDIX E

VAN HIELE GEOMETRY TEST

(VHGT)

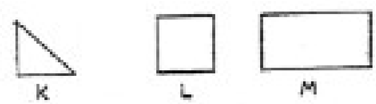
EXAMPLE QUESTIONS FROM THE FIRST GROUP OF FIVE QUESTIONS

REPRESENTING THE FIRST VAN HIELE LEVEL: RECOGNITION

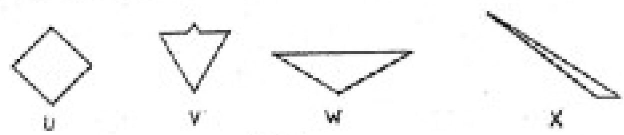
VAN HIELE GEOMETRY TEST

1. Which of these are squares?

   (A) K only
   (B) L only
   (C) M only
   (D) L and M only
   (E) All are squares.

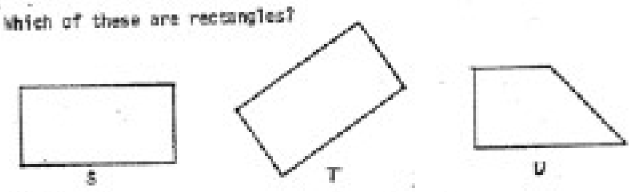


2. Which of these are triangles?



   (A) None of these are triangles.
   (B) V only
   (C) W only
   (D) W and X only
   (E) V and W only

3. Which of these are rectangles?



   (A) S only
   (B) T only
   (C) S and T only
   (D) S and U only
   (E) All are rectangles.

APPENDIX F

SPATIAL THINKING ATTITUDE SURVEY

(STAS)

SPATIAL THINKING
ATTITUDE SURVEY

Spatial thinking is a combination of a person's intuition with respect to direction, distance, location, pattern and shape and the relationships among direction, distance, location, pattern and shape, as well as a person's ability to visualize and manipulate direction, distance, location, pattern and shape in space.

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate number to the right of the statement.

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

1. Achievement in mathematics is directly related to spatial thinking ability.	1	2	3	4	5
2. Spatial thinking skills are important for students to be successful at the elementary school level.	1	2	3	4	5
3. I am sure that I can improve my spatial thinking abilities.	1	2	3	4	5
4. Spatial thinking skills are useful in other areas besides mathematics.	1	2	3	4	5
5. Spatial thinking skills can be developed.	1	2	3	4	5
6. I will incorporate spatial thinking activities into the classroom.	1	2	3	4	5
7. Spatial thinking skills are important in order for students to be successful in math at the high school level.	1	2	3	4	5
8. I believe that I will need to have good spatial thinking skills for my future.	1	2	3	4	5
9. There are some manipulatives that can encourage the development of spatial thinking.	1	2	3	4	5
10. I can see spatial thinking in many aspects of my daily life.	1	2	3	4	5

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate number to the right of the statement.

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

11. I am confident that I can draw geometric shapes accurately.	1	2	3	4	5
12. When I am asked to picture a three-dimensional object, I have a hard time.	1	2	3	4	5
13. Manipulating shapes in my head is challenging.	1	2	3	4	5
14. I struggle drawing two-dimensional shapes.	1	2	3	4	5
15. I struggle drawing three-dimensional shapes.	1	2	3	4	5

APPENDIX G

SEMI-STRUCTURED INTERVIEW PROTOCAL

Pre-Interview Questions

I. Spatial thinking

1) How would you describe spatial thinking?
2) Thinking back to previous experiences, can you identify instances where you:
    a) Used spatial thinking?
    b) Were taught spatial thinking skills?
    c) Were in a situation where spatial thinking was being emphasized?
3) How would you describe your ability with respect to spatial thinking?
4) Do you believe your spatial thinking skills can be improved?
5) Do you think spatial thinking skills are important in general? Why or why not?
6) Do you think spatial thinking is an important aspect of being a good elementary teacher?
7) What toys did you play with when you were younger? Video games? Computer games?
8) How would you describe your ability to draw geometric figures?
9) Thinking back to previous experiences, can you identify instances where you:
    a) Were expected to draw geometric figures?
    b) Were taught to draw geometric figures?
    c) Were in a situation where you knew if you could draw the geometric figure that would help you to answer a question?
10) Do you think that being able to draw geometric figures is important in everyday life? Why or why not?
11) Do you think that being able to draw geometric figures is an important skill for elementary teachers? What about other teachers?

II. Geometric thinking

12) Is there a connection between drawing geometric figures and using geometric vocabulary?
13) How would you describe the difference between “everyday geometric vocabulary” and “mathematical geometric vocabulary”?
14) Do you believe the expression “Mathematics is a language” to be true?
15) If yes, than what does this expression imply to you?
16) If no, then why not?
17) How would you describe your use of everyday geometric vocabulary verses your use of mathematical geometric vocabulary?
18) If elementary students tend to use everyday geometric vocabulary to identify geometric shapes is it important for the teacher to emphasize the use of mathematical geometric vocabulary? Why or why not?
19) How do you feel about your ability to use mathematical geometric vocabulary?
20) How would you describe geometric thinking?
21) How would you describe your ability with respect to geometric thinking?

22) If you were asked to choose the correct statement: “All squares are rectangles but not all rectangles are squares” or “All rectangles are squares but not all squares are rectangles”, how would you feel?
23) Does determining the accuracy of the statements given above have any connection to
    a) Mathematical geometric vocabulary? Why or why not?
    b) Drawing geometric figures? Why or why not?
24) Thinking back to previous experiences, can you identify instances where you:
    a) Used geometric thinking?
    b) Were taught geometric thinking?
    c) Were in a situation where geometric thinking was being emphasized?
25) Please tell me of your experiences pertaining to geometry
    a) Before you began school
    b) In elementary school
    c) In middle school
    d) In high school
    e) In college

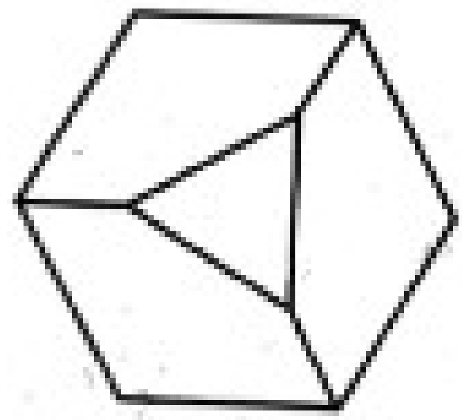
Post-Interview Questions:

26) Do you feel as though the *Quick draw* activity had any influence on
    a) Drawing 2-D geometric shapes?
    b) Drawing 3-D geometric shapes?
    c) Your geometric vocabulary?
    d) Your geometric thinking?
    e) Your spatial thinking/ability?
    f) Your beliefs and views regarding spatial thinking?
    g) Your confidence in your spatial ability?
27) What are your thoughts regarding the *Quick Draw* activity?

APPENDIX H

QUICK DRAW WRITTEN RESPONSE

(WR)



Quick Draw #1

Draw the figure.

What did you see first?

What else do you see?

How do you feel about your representation of the Quick Draw as compared to the actual Quick Draw?

APPENDIX I

JOURNAL PROMPTS

Pseudonym ______________________________________
Journal Prompt #1

What are your first thoughts when you are asked to draw geometric figures such as those in the Quick Draw activity? Please explain ;-)

Pseudonym ____
Journal Prompt #2

How comfortable are you with geometric vocabulary and identifying geometric shapes accurately?
Please explain.

Pseudonym ______________________________

Journal Prompt #3

1 Do you feel your spatial thinking skills have improved throughout the semester? Please explain.

2 Do you feel your ability to draw geometric figures has improved throughout the semester?

Please explain.

3 Do you feel your geometric vocabulary has improved throughout the semester? Please explain.

4 Do you feel your ability to see a variety of geometric figures embedded in the Quick Draw activities has increased throughout the semester? Please explain.

5 If you responded yes to any of the questions above, what might you attribute this improvement to? Why? Please explain.

APPENDIX J

GEOMETRIC VOCABULARY TEST (GV)

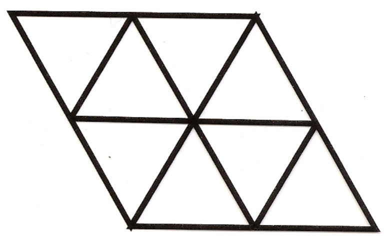
And

A LIST OF POTENTIAL GEOMETRIC SHAPES AND TERMS FOR THE GV

ID ______________________ Date __________________

Geometric Vocabulary

Using the following figure list all of the geometric terms and geometric shapes that you can identify.



List of potential geometric shapes and terms for the Geometric Vocabulary test (GV) as identified by two university mathematics professors.

Shapes	Terms
Triangle	Point
Isosceles triangle	Vertex
Equilateral triangle	Line
Trapezoid	Intersecting lines
Isosceles trapezoid	Parallel lines
Parallelogram	Transversal
Rhombus	Diagonal
Kite	Angle
Quadrilateral	60° angle
Pentagon	Acute angle
Hexagon	Obtuse angle
Septagon	Straight angle
Heptagon	Alternate interior angles
Polygon	Alternate exterior angles
	Vertical angles
	Corresponding angles
	Concave (polygon)
	Convex (polygon)
	Regular (polygon)
	Congruent (line segments, angles, or shapes)
	Similar (triangles, rhombuses)
	Symmetry
	Tessellation

VITA

Adele Elizabeth Conahan Hanlon

Candidate for the Degree of

Doctor of Philosophy

Dissertation: INVESTIGATING THE INFLUENCE OF *QUICK DRAW* ON PRE-SERVICE ELEMENTARY TEACHERS BELIEFS, IN CONCORDANCE WITH SPATIAL AND GEOMETRIC THINKING: A MIXED METHODS STUDY

Major Field: Professional Education Studies, Mathematics Education

Education:

May 2010: Doctorate of Philosophy, Professional Education Studies with a focus on Mathematics Education, Oklahoma State University.
1992: Masters of Education with an emphasis in Mathematics, University of Central Oklahoma.
1982: Bachelors of Science in Chemical Engineering, University of Tennessee.

Experience:

2000-2010: Lecturer of Mathematics, University of Central Oklahoma, Edmond, Oklahoma.
1991-2000: Adjunct Professor of Mathematics, Oklahoma Christian University, Edmond, Oklahoma.
1990-1993: Adjunct Professor of Mathematics, Oklahoma State University, Oklahoma City, Oklahoma.
1988-1989: Adjunct Professor of Mathematics, Florida Keys Community College, Key West.
1985-1988: Teacher of High School Mathematics, Academy of Our Lady of Guam, Agana, Guam.
1983-1984: Teacher of Middle School Mathematics, Saint Josephs Catholic School, Beeville, Texas.

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Name: Adele Elizabeth Conahan Hanlon Date of Degree: May, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INVESTIGATING THE INFLUENCE OF *QUICK DRAW* ON PRE-SERVICE ELEMENTARY TEACHERS BELIEFS, IN CONCORDANCE WITH SPATIAL AND GEOMETRIC THINKING A MIXED METHODS STUDY

Pages in Study: 177 Candidate for the Degree Doctor of Philosophy

Major Field: Professional Education with a focus on Mathematics Education

Scope and Method of Study: This embedded quasi-experimental mixed methods study investigated pre-service elementary teachers for the purpose of understanding the influence of an activity called *Quick Draw* with respect to their geometric thinking, spatial thinking, beliefs regarding spatial thinking, and additionally, their general awareness of spatial and geometric thinking.

Findings and Conclusions: Analyses of variance revealed no significant differences between mean scores of the Van Hiele Geometry Test, Geometric Vocabulary Test, Purdue Spatial Visualization Test, and the Spatial Thinking Attitude Survey with regard to the control and treatment groups of pre-service elementary teachers. Analysis of the qualitative data suggests that the treatment group did feel as though participating in the *Quick Draw* activities improved their geometric vocabulary, spatial thinking, and ability to draw the representations of the *Quick Draw* figures. This was accomplished through the integrated experiences of “discussion,” with respect to “dimension,” “parts,” and “names” as contributing factors in the development of their spatial representation skills; thus improving how they organized, constructed, and described the geometric figures; training them to think more spatially. Furthermore, McNemar’s test showed a significant increase in the use of the word rhombus in the treatment class establishing a relationship between the *Quick Draw* activity and Vygotsky’s Zone of Proximal Development. Pre-service elementary teachers’ views regarding geometric thinking were initially connected to the idea of shape, and they felt as though they were not comfortable with geometric vocabulary. The more comfortable the pre-service elementary teacher was with their own spatial ability, the more applications they saw in aspects of spatial thinking. The more aware the pre-service elementary teacher was of their own spatial thinking, the more emphasis they believed should be placed on the integration of spatial thinking into the elementary curriculum. Overall, pre-service elementary teachers would benefit from an integration of spatial thinking concepts and activities into their curriculum.

ADVISOR’S APPROVAL: Dr. Juliana Utley