TRICOT II, THOMAS ALEXANDER, Ph.D. Instructional Geographic Information Science: Map Overlay and Spatial Abilities. (2010)
Directed by Dr. Rick L. Bunch. 198 pp.

The fundamental goal of this study is to determine if the complex spatial concept of map overlay can be effectively learned by young adolescents through the utilization of an instructional technique based within the foundations of Instructional Geographic Information Science (InGIScience). Percent correct and reaction times were the measures used to analyze the ability of young adolescents to learn the intersect, erase, and union functions of map overlay. The ability to solve for missing inputs, output, or function was also analyzed. Young adolescents of the test group scored higher percent correct and recorded faster reaction times than those of the control group or adults of the expert group by the end of the experiment. The intersect function of map overlay was more difficult in terms of percent correct and reaction time than the erase or union functions. Solving for the first or second input consistently resulted in lower percent correct and higher reaction times throughout the experiment. No overall performance differences were shown to exist between males and females. Results of a subjective "real-world" test also indicated learning by young adolescents. This study has shown that the practice of repetitive instruction and testing has proven effective for enhancing spatial abilities with regard to the map overlay concept. This study found that with practice, young adolescents can learn the map overlay concept and perform at levels equal to or greater than adults. This study has helped to answer the question of whether this development of spatial abilities is possible.

INSTRUCTIONAL GEOGRAPHIC INFORMATION SCIENCE:

MAP OVERLAY AND SPATIAL ABILITIES

by

Thomas Alexander Tricot II

A Dissertation Submitted to
the Faculty of The Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Greensboro
2010

Approved by

____
Committee Chair

To

Alexander, Christopher, and Nicolas

Geography is everywhere.

and

To

Nicole

Your patience, understanding, and support have made all of this possible.

APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of The Graduate School at The University of North Carolina at Greensboro.

Committee Chair ____________________________________

Committee Members ____________________________________

____

____

____
Date of Acceptance by Committee

____
Date of Final Oral Examination

ACKNOWLEDGEMENTS

I wish to thank the members of my committee for their roles in making this study possible. I thank Dr. Jeffrey Patton for encouraging me to pursue doctoral studies in Geography. I thank Dr. Elisabeth Nelson for her guidance during the inception and early development of this study. I thank Dr. Michael Kane for his insight and suggestions throughout the study from a Psychology perspective. I owe my deepest gratitude to the committee chairman, Dr. Rick Bunch. Your guidance and mentoring throughout the entire dissertation project have demonstrated what it means to conduct quality research. The completion of this study would not have been possible without your help.

I would also like to thank the faculty and administration of Saint Pius X Catholic Middle School for their cooperation and helpfulness during the experimental and data collection portion of this study.

Lastly, I offer my thanks to all of those family, friends, and coworkers who supported me in many respects during the completion of this study.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Scientists educated in the discipline of geography are uniquely proficient in their ability to analyze questions and problems from a spatial perspective or geographic point of view. Professional geographers hold this ‘geographic thinking’ in high regard in business and academia alike. John D. Nystuen, a pioneer in spatial analysis and modern mathematical geography, defined the key concepts needed to establish this way of thinking. Directional orientation, distance, and connectiveness became the axioms of the spatial point of view (Nystuen, 1968). Those who incorporate these geographic axioms within their knowledge base have a greater advantage in their ability to reason in world connections that are becoming ever-increasingly global. Despite intellectual advances in the theories and concepts of this spatial point of view and their importance to the critical thinking abilities of a global society, our educational system has been slow to incorporate geographic knowledge into the curriculum of our schools. More than a century ago, the importance of an education in geographic thought was known to be important. In an address delivered at the Annual Meeting of the Geographical Association on January 15, 1902, the Right Hon. James Bryce declared, “geography in one aspect is the gateway to the physical sciences; in the second aspect it is the key to history; and in the third it is the basis of commerce” (Bryce, 1902, p.301). One hundred years later, Sir Ron Cooke stated during his presidential address at the Royal Geographical Society’s annual meeting, “geography is fundamental to understanding such enduring issues as social equity, globalisation, and the relations between environment and society” (Cooke, 2002). The critical need for a continued call to arms for geographic education throughout the 1900s and into the twenty-first century illustrates the very slow progress made for the meaningful incorporation of geographic knowledge into classrooms.

The Association of American Geographers states the greatest value of a geographic education lies in its ability to prepare students for post-secondary education and a vast array of potential careers (Gallagher, 2010). Studies show that there is a lack of geographic education taking place in secondary education (Ligocki, 1982; Kopec, 1984). Kopec tested over 2,000 introductory level geography students and recorded a greater than 90 percent failure rate. In fact, 73 percent of Kopec’s subjects stated to never having taken a geography class in high school. Former Educational Affairs Director of the Association of American Geographers, Salvatore J. Natoli, argues for the incorporation of geography courses in secondary education to improve conceptual principles and skill learning essential for coping with our changing world (Natoli, 1985). The National Council for Geographic Education specifically refers to skills acquired by students who are exposed to a geography education,

> They are able to use data from maps, tables, graphs, and text to recognize patterns and solve problems. Students also can integrate concepts from many different areas of science, social science, and the humanities, and apply critical thinking to understanding and dealing with current issues of local, national, and international importance. (Shirey, 1994, p.4)

According to Golledge and Stimson (1997), spatial visualization, spatial orientation, and spatial relations are three dimensions to spatial thinking. Spatial relations, which include abilities such as map overlay, regionalizing, and wayfinding, warrants the major focus within geography instruction of secondary education due to the significance of these components in everyday spatial behavior (Golledge & Stimson, 1997). It is, therefore, of the utmost importance that this thinking from a spatial perspective be incorporated into the analytical thinking abilities of today's secondary education youth.

During the 1980s, the Geography Education National Implementation Project (GENIP) was established to assess the breadth and depth to which geography and its concepts were being translated to students through the nation's educational system. The National Geographic Society assembled allegiances with many other organizations to develop a national network of interest in geography education. A poll conducted in 1988 by the Gallup Organization found that Americans were far below acceptable levels in terms of geographic literacy. In 1989, geography standards did not exist within the secondary education curricula for any state in the nation (Daley, 2003). A significant turnaround for geography education, however, occurred in 1994. The Geography Education Standards Project (GESP) was completed, resulting in a list of educational standards for the instruction of geographic thought within American schools. With grants from the U.S. Department of Education, the National Endowment for the Humanities, and the National Geographic Society, four principal organizations worked together to establish these educational standards. These organizations were the American Geographical Society, the Association of American Geographers, the National Council for Geographic Education, and the National Geographic Society (Bednarz et al., 1994). The organizations involved with the development and funding of these standards illustrates the importance and seriousness with which the needs for the standards were and continue to be perceived. The standards serve as educational and intellectual goals for which students should strive to achieve. The first foundational element of which the standards are organized is the ability to understand the world in spatial terms. People use geographic tools such as maps, photographs, and satellite images to investigate the relationships between people, places, and environments. These tools display information in a spatial context. There are three standards that are derived from the use of these tools: 1) How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective; 2) How to use mental maps to organize information about people, places, and environments in a spatial context; and 3) How to analyze the spatial organization of people, places, and environments on Earth's surface (Bednarz et al., 1994, p.61-68). The importance placed on acquiring spatial skills by the first three GESP standards emphasizes an overall goal of enhancing the spatial abilities of today’s youth. It is the application of these learned skills that allows for the ability to critically apply geographic and spatial concepts to real-world issues across various intellectual disciplines.

Also of note is the incorporation of geography as a “core academic subject” within the No Child Left Behind Act (NCLB) of 2002, formerly known as the Elementary and Secondary Education Act (ESEA). Although the title may sound grand, there are actually two distinct groups of core subjects, each requiring different levels of academic scrutiny. Geography is listed as a core subject, but is within the group whose standards and assessments are optional and under each individual state's control. In fact, geography is the only discipline without a dedicated program of provisions by the NCLB. Geography finds itself in the position of a catch-22. NCLB measures student achievement by the use of mandatory state assessments, however, most of these assessments lack geography-related content, which mirrors the level of geography content in the classroom. Thus, the only way to be taught the material is to be tested on that material, and in order to be tested on the material, a student must be taught the material. Geography must find a way to situate itself alongside the other disciplines of the Act if future funding is to be secured. To do this, the discipline must fulfill the two top priorities for all programs: improving the academic achievement of students and providing high quality instructors. Within the discipline of Education, emphasis is traditionally placed on those programs whose curricula are the product of scientifically based research (Daley, 2003). The best way to show geography's merit is to illustrate its unique and necessary role in the education of our children and to demonstrate students' effective learning of spatial skills through empirical research.

Jacobs (1989) and Audet and Abegg (1996) believe that an interdisciplinary approach to learning may be effective in helping students to develop problem-solving skills. In fact, concurrent with the 1994 inception of the national geography standards, the field of education has progressed toward inquiry-based instruction with an emphasis on research-based learning experiences. The constructivism learning theory from which this is based holds that knowledge is created by the learner's experiences as opposed to being handed down from the teacher (Driver et al., 1994). Students in contact with this inquiry approach are better prepared to form research questions, develop methodologies, gather and analyze data, and draw conclusions (Bednarz et al., 1994).

The incorporation of geographic knowledge into the curricula of secondary education via inquiry-based instruction has made great advances over the past two decades. Traditional methods of instruction and assessment stressed only the learning of selected facts such as the names and locations of state capitols and rivers (Ediger, 2001). Recent programs such as The Partnership for 21st Century Skills have integrated the skills of problem solving, communication, and critical thinking into geography classes. The 21st Century Skills and Geography Map identifies methods for educators to incorporate technology and geographic thinking skills into existing curricula (Nagel, 2009). Throughout the 1990s and into the early 2000s, the number of students taking high school Geography courses increased two- and three-fold in the states of Texas and Tennessee (Bednarz, 2002). There is still much work to be done if the richness of spatial analytical techniques is to help today's youth make the informative decisions needed for future success in our global society. As of 2005, the extent to which the discipline of geography was incorporating this critical thinking ability to the youth of the nation was very limited. Of the 22 states that required examinations in order to graduate from high school, only seven included tests on aspects of geography (Daley, 2003). According to a study performed by National Geographic, in 2005 there were only eight states that required a geography course to be taught in the high school curriculum. Of these, only five actually required the instruction of geography as a stand-alone subject without the incorporation of topics within the general heading of social studies (Rutherford, 2008) (Table 1).

Table 1. Required Geography Courses within Secondary Education.

Requirements	# of States[1]	% of Total
Geography exam for graduation[2]	7	14%
Geography material only taught within Social Studies course[3]	3	6%
Stand-alone Geography Course	5	10%

Conspicuously underrepresented within the GESP and the curricula of secondary education programs across the nation is the role of the geographic information system (GIS). One reason for this near omission is the date of publication. In 1994, GIS was still being developed and had yet to be fully scrutinized by the geographic and educational community. It was initially heralded as a tool to utilize the rapid and repeatable analysis inherent in geographical studies (Bednarz et al., 1994). However, over the past several decades, GIS has evolved into a field of study called Geographic Information Science (GIScience). GIScience is a field of inquiry that provides the scientific context for conducting research related to GIS. (Goodchild, 1991; 1992; Johnston, 2004). As geographic analysis becomes incorporated into the curricula of American schools, a pedagogical approach to the instruction of this type of analysis and thinking is paramount. Whether 'geographic thinking' can be effectively introduced into

[1] Including District of Columbia
[2] Daley, 2003
[3] Rutherford, 2008

secondary education by the use of GIS as a tool within the current curriculum continues to be a crucial question in need of an answer.

The role of GIS in secondary education, although heralded and accepted by some, has not yet been fully implemented into the curricula of our nation's middle and high schools. The reasons for this lack of implementation are both academic and administrative. Since the inception of NCLB, teachers have been encouraged to focus classroom instruction on materials that will be tested by state standards assessments. If geography is underrepresented on these tests, as is often the case, then less time will be directed to geographic concepts during classroom instruction. To compound this dilemma, there are many perceived barriers to the incorporation of GIS into classrooms. In addition to hardware and software costs, the chief challenges most educators face in implementing GIS are a lack of training and support for the teachers, a lack of time to develop appropriate lesson plans, and the complexity of the software. The latest data suggests that less than 2 percent of America's secondary education schools had implemented GIS into their curricula (Kerski, 2003). At the time of this study, however, no recent studies were available to confirm the current state of adoption rates. It would be reasonable to assume that these rates have increased dramatically especially when considering the rise in awareness and employment demands for individuals who can think spatially and use GIS (Gewin, 2004).

These restraints on GIS implementation and expansion are worth overcoming. Palladino (1994) posited that despite its inherent spatial reasoning incentives, GIS can be utilized to enhance various teaching methods, to provide better delivery of subject matter than textbooks alone, and to prepare students for spatial technologies in the workforce. According to Sarnoff (2000), the incorporation of GIS may encourage students to simultaneously examine data from a variety of fields, thus exercising their critical thinking skills by incorporating spatial concepts. The Geography Education Standards Project Team (Bednarz et al., 1994, p.256) stated, “The power of a GIS is that it allows us to ask questions of data.” GIS lessons are often constructivist and interdisciplinary in nature. This allows emphasis to be placed on the content area rather than on the system itself. Under such conditions, students should be able to learn the material being presented with little distraction from the actual computer system interface (Kerski, 2003).

CHAPTER II

LITERATURE REVIEW

Skills, Abilities, and Practice

It is important to understand the relationship between abilities and skills with respect to spatial concepts. In the purest sense, skills are learned activities that contribute to the development and expression of abilities. Spatial abilities consist of the use of spatial skills in activities such as "representing, transforming, generating, and recalling symbolic, nonlinguistic information" (Cherney, 2008, p.776). One may say they have the *ability* to understand a map because they have acquired and are able to utilize map reading *skills* such as how to use the scale, legends, symbology, colors, and orientation. This skill-ability relationship can be demonstrated by assuming a group of unskilled subjects, who might have a range of spatial abilities, but have not previously viewed a particular map. A researcher could monitor their performances as they learn information on the map. This information becomes prior knowledge which they can use to enhance subsequent performances of the same task. They have acquired a skill from the experiences that enhances performance. If they perform the task significantly faster, more accurately, and with less perceived difficulty, then they have learned something that enhanced performance. Spatial abilities can be improved through the acquisition of task-relevant skills (Cherney, 2008).

Given this relationship, many studies have focused on various methods to deliver spatial information in ways that will most effectively foster the development of spatial skills (Terlecki & Newcombe, 2005; Cherney, 2008). Terlecki and Newcombe (2005) found that training (formal instruction) of spatial skills proved effective at enhancing spatial abilities to the point where undergraduate students had still not reached a "leveling off" point after a semester of research. They were able to show that experience with computer gaming substantially mediated an observed pre-test divide between males and females on mental rotation tests. Other recent studies have found that students may become skilled at performing a spatial task by additional practice doing the task (Casey, 1996; Lloyd & Bunch, 2005; Cherney, 2008). Practice (repeated use) of spatial skills proved as the significant factor in Cherney and Neff's (2004) observation of higher test results for students who had previously completed mental rotation tests. Although males were found to perform significantly better than females as a group, significant sex-based differences did not exist when accounting for prior experience with mental rotation tests. Previous test-taking experiences appear to have served as effective practice with respect to mental rotation tasks. Several studies over the past two decades have observed that playing video games as a surrogate to training and practice have proven as a successful means of improving spatial skills (Subrahmanyam & Greenfield, 1994; Terlecki & Newcombe, 2005; Terlecki et al., 2007; Cherney, 2008). Cherney (2008) tested the impacts of computer game practice on mental rotation abilities between males and females. She found that the gains by females were significantly higher than males. She states that this is confirmation that spatial abilities are malleable regardless of an individual's sex. The idea that training and practice could enhance an individual's spatial abilities is not new, and was realized long before the age of computer gaming. Spatial exploration has been shown to essentially be a method of practice. Brown and Broadway (1981) found that regardless of sex, the accuracy of cognitive (mental) maps of adolescents was correlated to the amount of experience with automobile driving performed by the subjects. This may help to explain how social constructs have played a role in early studies showing females as less spatially-minded than males. The results of these studies may also indicate that practice is effective at closing this difference. Connor and others (1978) showed in an earlier study that this sex-based gap could be eliminated through training. Females scored higher, although not significantly, than males on a task of finding embedded figures. The underlying determinant of an individual's spatial abilities may be more than just a matter of sex. Females show comparable abilities to males once skills are developed. Training and practice appear to be able to "level the playing field." Based on these and other similar findings, Cherney (2008) calls for additional research identifying various forms of training and practice that enhance growth in spatial abilities. Newcombe and others (2002) posited the question of whether it was more important to find ways of enhancing spatial abilities than determining how these abilities are different between individuals and the sexes. If it is more than just a mere male/female difference that explains differing spatial abilities between individuals, then perhaps such research needs to take place.

Individual Differences

The individual differences among people are of considerable importance when examining the acquisition of spatial skills. Early cognition studies of spatial abilities were conducted in the field of psychology and resulted in findings that males tended to be superior with respect to some tests of spatial abilities (Maccoby & Jacklin, 1974; Harris 1981). There was a subsequent need for geographers to extend and translate this research into the arena of map reading skills. Stereotypes alluding to the superiority of males over females with regard to spatial abilities had already begun to pervade geographic literature (Roder, 1977). In a study of urban planning map construction, Stringer (1973, p.90) altered the experimental design to include only female test subjects because he "expected that women would have greater difficulty than men in reading maps."

Early studies by geographers focusing on sex-based spatial ability differences resulted in similar conclusions (Halpern, 2000; Linn & Petersen, 1985), however, with some mixed results. Gilmartin and Patton's (1984) study of map-use skills by elementary school students showed significant differences by grade level only with the exception of first grade students whose males performed significantly better on symbol identification. Their explanation as to why the only significant difference was found at the youngest level was due to experiential factors resulting from the children's early life play activities. This explanation fit neatly into the category of environmental, or social, factors that play a determining role in the development of differing spatial skills between the sexes. Nash (1979) noted that due to the increased amount of time spent outdoors, males tend to be steered towards different toy play and outdoor activities than females. Halpern (1992) called for pointed research into the root of this nature-nurture (biological-environmental) role of sex-based spatial ability differences. Both environmental (sex-role stereotypes) and biological (handedness, laterality) measures needed to be fully researched in hopes of developing solid foundational theories. This was the means to capture the true nature of cognitive sex differences. The nature-nurture debate began to expand as researchers sought to find the root causes of these differences.

Although the causes and explanations of sex-based differences are still not fully realized, years of research has narrowed this belief to denote that males and females tend to excel more than the other dependent upon the specific type of spatial ability being tested. Males tend to excel at processing images in their working memory (Halpern & Crothers, 1997; Linn & Petersen, 1985) on tasks such as mental rotation (Cherney & Collaer, 2005; Linn & Petersen, 1985; Voyer et al., 1995; Halpern, 2000), spatial perception (Liben & Golbeck, 1980; Linn & Petersen, 1985), and judgments of movements (Law et al., 1993), horizontality/verticality (Linn & Petersen, 1985), and line angle/position (Cherney et al., 2006). Loring-Meier and Halpern (1999) found mixed results when testing the working memory of males and females. Males were able to more quickly process tasks such as visual image generation, maintenance, scanning, and transformation, while females demonstrated the ability to complete the tasks with greater accuracy. Females have been shown to excel at the acquisition of spatial information from their long-term memory (Galea & Kimura, 1993; Choi & Silverman, 2003) at tasks such as recalling spatial arrays (James & Kimura, 1997).

To add to an already complicated matter, some researchers believe that an individual's gender identification may be a more accurate identifier of one's spatial abilities. Lloyd and Bunch (2008) suggested why gender may be a more suitable independent variable than sex in models designed to explain performance on spatial tasks. Studies that have directly considered gender as an independent variable have indicated females who scored higher on the masculinity scale also scored higher on a variety of spatial performance tasks (Signorella & Jamison, 1986; Jamison & Signorella, 1987). Casey (1996) argued a female's gender identity is likely to guide interests in the activities that would provide practice in the form of spatial exploration. Saucier and others (2002) suggested that gender role socialization could mediate sex differences in spatial tasks requiring mental rotation. Lloyd and Bunch (2008) used the Bem Sex Role Inventory (BSRI) (Bem, 1974) to measure positions along masculinity and femininity scales for subjects performing a search task for states on a US map. The results suggested a complex relationship existed between gender and task performance. Reaction time results indicated the fastest performance on the search task was for subjects that scored higher than typical on both the masculinity and femininity scales. Accuracy results indicated the most accurate performance was for subjects that scored lower than typical on both the masculinity and femininity scales. While decades of research indicate that there exists undeniable differences in the spatial abilities between males and females, both masculine and feminine, absolute conclusions cannot be made based on sex and gender alone. The search for deeper biological differences has extended the investigation into the root of individual differences.

Studies of biological causes of individual differences typically fall within two categories, hormone effects and brain organization. Hormonal levels have been shown to be a contributing factor to individual differences in spatial abilities. Early studies showed positive correlations between the male hormone androgen and spatial skills (McGee, 1979). It was observed that as androgen levels fluctuated throughout adolescence, so did performance on spatial tasks. Testosterone levels have also shown correlation with higher spatial abilities when at moderate (high for women and low for men) levels (Gouchie & Kimura, 1991; Bell & Saucier, 2004). Brosnan (2006) suggests that prenatal testosterone may curtail growth of the left hemisphere of the brain while enhancing growth of the right hemisphere. This unequal development of the brain may lead to observations described in the concept of brain lateralization or asymmetry. Manning and others (1998) indicate that prenatal testosterone levels are reflected in the length of the fourth digit (4D), or ring finger. Prenatal oestrogen levels are similarly reflected in the length of the second digit (2D), or index finger. Given the effects of prenatal testosterone on hemispheric development, the 2D/4D ratio may serve as an indicator of spatial ability (Falter et al., 2006). Recent studies have shown correlation between the 2D/4D ratio and higher spatial abilities of males versus females (Loehlin et al., 2006; Bunch, 2008).

The consideration of brain organization as a contributing factor in the biological realm began with studies describing a lateralization of the brain (Sherman, 1978; Annett, 1985). Sherman (1978) indicated that the two hemispheres of the brain were functionally specialized. With regard to map-reading abilities, Kosslyn and others (1998) explain that the left hemisphere specializes in verbal abilities and stores categorical information such as the relative location of objects to one another across a map or throughout space. The right hemisphere specializes in visual, or spatial, abilities and stores coordinate information such as specific horizontal and vertical placement of objects on a map. Bunch (2010) supported the idea of hemispheric differences when he observed that participants who searched for well-known cities on a map encoded coordinate information while those searching for novel cities encoded categorical information. He also noted differences for encoding tendencies between males (coordinate) and females (categorical). Recent medical research has furthered this concept of lateralization of cognitive processes across the brain through identification via functional magnetic resonance imaging (fMRI) (Slotnick and Moo, 2006).

Another physiological explanation for observed individual differences is the notion that a person's genetic makeup predetermines specific cognitive abilities. Two dominant theories explaining such an innate spatial ability include the Right Shift Theory (Annett, 1985; 2002) and Bent Twig Theory (Sherman, 1978). Annett (1985) hypothesized a gene for brain lateralization that determined left or right hemisphere dominance resulting in traits such as handedness, and a propensity for verbal or spatial abilities. Her Right Shift Theory suggests that right-handed persons who have non-right-handed immediate family members are more likely to have enhanced spatial abilities than persons with only right-handed relatives. Sherman (1978) initially proposed an interaction between biological and environmental components to explain differences in spatial abilities between males and females. Based on the old saying, "As the twig is bent, so grows the tree," she hypothesized that as males were more inclined to participate in spatial activities due to environmental factors, their spatial abilities would be passed down to their children who in turn would have advantages to develop spatial abilities based on these same environmental factors and inherited traits. Casey (1996) used Right Shift Theory to explain the genetic component of the Bent Twig Theory. Person's who possess the heterozygotic genotype defined by Right Shift Theory are capable of attaining enhanced spatial abilities if substantial spatial experiences are actualized. She concluded that females, as well as males, could have high spatial abilities if both biological and environmental factors were present.

Additional research focusing on brain organization considers the effect of the limited capacity of a person's short-term, or working, memory. Baddeley (1986; 1998) and Sweller (1988) hold that this limited working memory is connected to the unlimited long-term memory that holds learned information. Cognitive Load Theory (CLT) seeks to explain the interaction between a learner's limited working memory and their unlimited long-term memory. The key to learning is directly dependent on the ability to foster greater utilization of the learner's working memory (Paas & Van Merrienboer, 1994). The idea is that information gathered through an individual's senses is processed in working memory before it is able to be stored as learned information or knowledge in long-term memory. Paas and others (2003) propose two categories of factors that affect a person's cognitive load. Causal factors include task-dependent variables such as task complexity and pace of instruction. Assessment factors include the components of mental load, mental effort, and performance. Mental load is task-centered and is determined by the given task and the environment. Mental effort is centered on the individual and refers to the cognitive capacity allocated to perform the task. Performance refers to the end result of the task. It serves as an indicator of the mental load and mental effort expended during task operations (Sweller et al., 1998; Sweller, 2004). These components together with any existing causal factors are measurable and serve to quantify cognitive load, the amount of information imposed on a learner's working memory. A person's cognitive load is further composed of three additive components. Intrinsic load is inherent in the material being learned. Extraneous load is that which is imposed by the learner's environment; this includes load imposed and manipulated by instructional methodologies. Germane load is that extra amount of working memory capacity that can be used to construct schemas, the mental constructs that allow learners to store information into long-term memory. Schemata can be conceptualized as a cognitive framework residing in long-term memory that holds task-specific information gathered through experiences for later use in solving problems. Paas and Van Merrienboer (1994, p.361) declare that this structure plays a functional role in learning because it, "enables problem solvers to recognize problems as belonging to a particular category requiring particular operations to reach a solution." This type of scenario occurs often in the act of reading maps (Schwartz et al., 1998). Maps of known locations are able to be simplified through the act of removing place names and other extraneous data if a schema has been developed that allow the user to identify locations across the map from knowledge held in long-term memory. In essence, as problem solvers utilize schema, they begin to draw upon this knowledge from long-term memory to solve similar problems, therefore freeing up critical cognitive load resources necessary for the further development of additional schemata. Working memory span tasks have been developed over the years (Turner & Engle, 1989; Fischer, 2001; Kane et al., 2004; Cowan & Morey, 2006) and have consistently been related to how well people perform real-world cognitive tasks and real-world variation in performance. Tests of working memory span typically require subjects to recall a series of verbal or spatial stimuli in the order originally presented. Lloyd and Bunch (2008) observed significant differences in search task accuracy between verbal and spatial memory span tests.

Finally, cognitive science researchers have recently distinguished a variety of cognitive styles to account for individual differences in performance on spatial tasks. The visualizer-verbalizer distinction suggests a preference for using either left-hemisphere verbal processing or right-hemisphere visual processing that could prove an advantage on specific tasks. Furthering this concept, Blazhenkova and Kozhevnikov (2009) recently suggested methods for distinguishing three cognitive styles that seem ideal for investigating map learning. Object visualizers construct high-resolution vivid images of individual objects and excel at object imagery tasks such as recognizing degraded pictures while spatial visualizers use imagery to represent and transform spatial relations and excel at spatial imagery tasks such as mental rotation and imagined paper folding (Motes et al., 2008). Verbalizers tend not to prefer using either object or spatial imagery. When processing a typical cartographic map one encounters visual information in the form of map symbols and some verbal information in the labels attached to the symbols. Research into cognitive styles is of specific interest to geographers since typical cartographic maps have a large amount of information that map readers must process as object properties such as the colors and shapes of map symbols, or spatial properties such as spatial locations and spatial relations.

The nature-nurture role within spatial abilities remains a topic of current research by psychologists and geographers. The many biological variables that may contribute to individual differences exist alongside the cultural and environmental variables within the fabric of our society. It is also clear that these and possibly many other undiscovered environmental and biological variables interact to determine both the foundational and potential level of spatial abilities within individuals. Wachs (1992) and Casey (1996) called for a more interactionist approach into the reasons for individual differences rather than relying solely upon observations of these main effects. Casey (1996, p.257) believes that research combining various environmental and biological variables "may allow for a more general research strategy which provides a better grasp of factors affecting individual differences in development." Geographers Lloyd and Bunch (2008) recently conducted this type of research in their study of the ability of undergraduate students to specify the location of the 48 contiguous states of the United States in random order as quickly and accurately as possible. Reaction time and percent correct were recorded for students classified according to gender, memory capacity, and brain asymmetry. Classifications were determined via BSRI, spatial and verbal working memory span tests, and 2D/4D ratios respectively. Regarding reaction time, significance was observed within the interaction of memory capacity and brain asymmetry. Significance in accuracy was found for the interactions of gender and brain asymmetry as well as memory capacity and brain asymmetry. Lloyd and Bunch (2008) call for future research to include additional variables such as Annett's RST and collect additional performance measurements such as self-efficacy assessments.

Instructional Geographic Information Science (InGIScience)

According to Bunch and others (2008), determining the most effective instructional methods for geographic education is based upon an understanding of the overlap between three academic disciplines inherent to this question: Geography, Education, and Psychology. The interaction between geography and education is illustrated by the many instructional tools and techniques, such as GIS, employed to facilitate geographic thinking. Geographic education is concerned with methods to teach the concepts of spatial visualization, spatial orientation, and spatial relations. Educational psychology aims to incorporate research from education and psychology to understand how people learn in an educational setting. The overlapping research in psychology and geography is the study of spatial cognition. The underlying goal of spatial cognitive studies is the understanding of how people store and retrieve spatial information in their minds. The answer to the question of how to facilitate geographic thinking in students can be found at the intersection of all three interdisciplinary subfields, and may be thought of as *Instructional Geographic Information Science (InGIScience)* (Bunch et al., 2008) (Figure 1). It is from this perspective that the current study approaches the underlying questions of how to effectively achieve development of spatial thinking in today's youth.

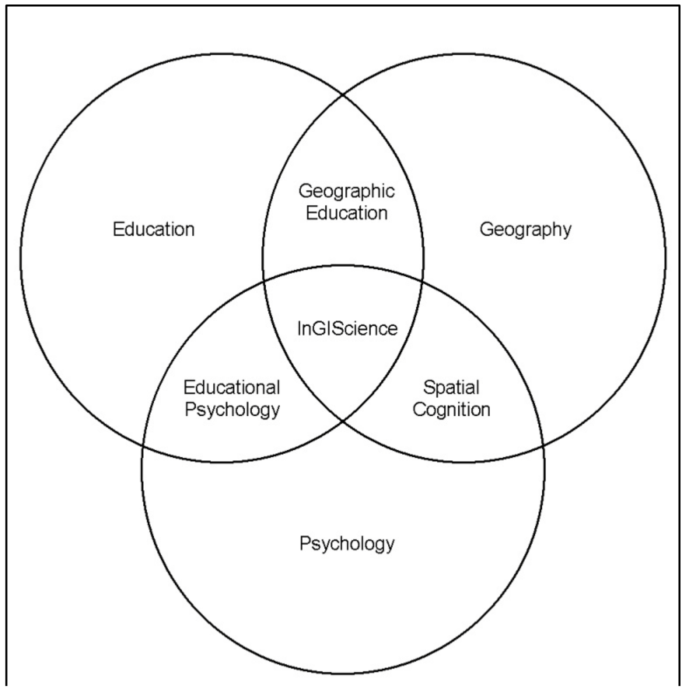


Figure 1. Instructional Geographic Information Science model (Bunch et al., 2008).

Geographic Education

Studies of the use of GIS as an educational tool can be divided into two camps; technological advancement and spatial thinking enhancement. Many recent studies have focused on the technological aspects of GIS incorporation into secondary education. They indicate that many students develop technology skills as opposed to the spatial analytical skills sought after by the implementation of GIS. Meyer and others (1999) illustrated the potential setback that a GIS software learning curve can place on students. Fifty-nine middle school young adolescents studying water quality issues were divided into GIS-based and traditional learning groups for more than six months. Throughout the instruction period, it was observed that the GIS group needed considerable time to learn the basic functions and capabilities of the GIS software. At the end of the study, no difference in learning was recorded between the group of students utilizing GIS and the traditional learning group. Qualitative measures indicated that cartographic output was the only merit of the GIS-incorporated lesson plans. Outcomes such as this have been linked by many to the barriers facing the introduction of GIS within the classroom, such as acquisition of hardware, software, and training of teachers (Bednarz, 2004; Meyer et al., 1999; Kerski, 2003). Surveys conducted by Kerski (2001; 2003) document the most common reasons teachers do not utilize GIS in the classroom as a lack of software training for teachers, lack of financial and technical support of hardware and software, and a lack of time to develop appropriate GIS lessons. These barriers raise questions about the usefulness of GIS as an educational tool.

Other studies have focused on the use of GIS as a way to enhance spatial thinking (Goodchild, 1993; Bednarz, 1994; Bednarz & Ludwig, 1997; Meyer et al., 1999). Fifth-grade students in Utah used a GIS to aid in a project using map overlay for an analysis of business site selection. Factors such as unemployment, serious crime, income, percentage poverty, and population were analyzed to determine the 'best' location for business location (Bednarz & Ludwig, 1997). Studies of the effectiveness of GIS in enhancing the learning of spatial reasoning for students have for the most part had mixed results. Albert and Golledge (1999) tested 127 undergraduate students for differences in spatial ability based on variables of GIS instruction and sex. Results showed no significant differences between GIS-users and non-users or males and females on tasks inherent to the map overlay concept. Lo and others (2002) incorporated GIS into an undergraduate interdisciplinary environmental project in hopes of stimulating critical thinking about the subject matter. Test results showed higher test scores for students who participated in the GIS supplemented field laboratories. In another study, Patterson and others (2003) used GIS technology to instruct and conduct a research study of ground cover classification with thirty high school students. These students were tested along with forty-eight undergraduate world regional geography students on seven specific state geography standards corresponding to the National Geography Standards. They found that although test scores were not as high as expected, high school students receiving instruction through GIS scored significantly higher on test materials than college students without GIS-based instruction. Kerski (2003) encountered mixed results when testing high school students. Students enrolled in geography courses in three high schools were divided into GIS-instructed and traditional instruction groups. They were tested on the geographic principles taught during each lesson, and at the end of the full academic year, they were given standardized and spatial analysis geography tests. No significant difference between groups was found with either the standardized or spatial analysis tests. End of grade test scores did suggest that average and below-average students improved more than above –average students within the GIS group. Significant differences were found with respect to content specific material taught during the geography lessons. Four out of nine lesson specific tests showed significant higher test scores and utilization of higher-order spatial and analytical thinking for the GIS group. According to Bednarz (2004), the results of these and other recent studies (Feeney, 2003; Kerski, 2003) indicate that the beneficial role of GIS in improving students' spatial thinking skills has not yet been completely realized. These research findings compel future GIS studies to place an importance on the age of students and on the type of material or test being presented.

Educational Psychology

Downs and Liben (1991) set the groundwork for linking theoretically based cognitive development with geographic expertise. They note that students have varying cognitive skills necessary for geographic thought. They may vary in their level of competence, ability to apply these competencies, or the models of how they perceive the world. They ask how geography lessons can be developed to be sensitive to the capabilities of the students. First, we must understand the cognitive and spatial skills necessary to master the geographic concept to be learned. We must also understand the cognitive level of the students being taught. With the knowledge of these cognitive requirements and levels, teaching strategies that account for these preconditions must be developed. This framework will aid in the creation of a platform from which geographic, and more specifically GIS, lessons can be created.

The answer to the question of how to determine the specific level of spatial cognitive ability necessary for a particular geographic concept lies in an area of study that has already proven successful for disciplines such as physics, mathematics, and computer programming (Paas & Van Gog, 2006). CLT is defined by Paas and Van Merrienboer (1994) as the concentration of instructional techniques development that allows the limited cognitive abilities of learners to apply learned knowledge to new situations. CLT explains that causal factors inherent to geographic questions include task conditions such as a multimedia or GIS environment and learner differences including an individual's sex and brain orientation. Such factors may have profound impacts during instruction and testing of complex spatial abilities inherent to geographic concepts. Sweller and others (1998; 2004) believe it is advantageous to develop instructional techniques that will have the effect of minimizing intrinsic and extraneous loads, thereby increasing the capacity of germane load available for schema acquisition. Since intrinsic load is inherent in the material being presented and is not directly controlled by the teacher, instruction techniques must be implemented that logically categorize and curtail the amount of information being presented in a particular lesson. Pass and Van Merrienboer (1994), for instance, highlight some initial approaches for reducing extraneous load, such as hierarchical, emphasis manipulation, goal-free problems, worked-out problems, completion strategies, and expert-like problems. These and more specific sequencing effects such as redundancy, split-attention, and modality are further discussed by Sweller and others (1998).

More recently, Salden and others (2006) demonstrated the advantages of whole-task versus part-task and dynamic versus static approaches to the learning of complex cognitive skills. Dynamic approaches have enabled the manipulation of intrinsic as well as extraneous load. The main approach employed by dynamics is the expertise reversal effect, which holds that the techniques used by novices lose their effectiveness as the novice learners become more expert-like (Paas et al., 2003). Scaffolding whole-task practices and just-in time information presentation are also means by which to decrease both intrinsic and extraneous cognitive loads (Van Merrienboer et al., 2003). Meanwhile, Renkl and Atkinson (2003) suggested a fading effect be incorporated into worked examples to account for changes in learner's expertise. Gerjets and Scheiter (2003) go one step further in allowing for the incorporation of learner as opposed to teacher instructional decisions as expert knowledge is gained.

Since 1992, Van Merrienboer and others have been developing an instructional design model based on the principles of CLT (Van Merrienboer et al., 1992; Van Merrienboer, 1997; Van Merrienboer et al., 2002). The Four-Component Instructional Design model (4C/ID) presumes that there are four components inherent in any well-designed learning environment: learning tasks, supportive information, procedural information, and part-task practice. Although some studies indicate that reliance on part-task approaches can be detrimental to complex learning (Kalyuga et al., 2003; Salden et al., 2006), if a very high level of automaticity is required as an outcome of the learning process, then the most efficient means of producing this is through repetition of part-task lessons (Van Merrienboer et al., 2003). These studies illustrate effective approaches to learning; however, they require a substantial investment of time by teachers for implementation. Curriculum development takes time, and this is unlikely given the history of consistent absence of geography in our state and national education standards. If and when appropriate funding and value are added towards the testing of geographic concepts, it is evident CLT has the potential to serve as the framework from which geography and GIS lessons could be developed to maximize learning outcomes.

Within a geographic context, maps have the capability of including multiple sources of information in the form of text and diagrams. Map readers are often required to integrate both forms of information simultaneously and this is likely to impose a heavy, extraneous cognitive load (Sweller et al., 1990). In the field of geography, early research by cartographers acknowledged the importance of improving the transmission of intended messages on maps. Cartographers made maps that focused attention only on material to be learned (Monmonier, 1974; Olson, 1975). Emphasis has also been placed on understanding the cognitive processes of map readers' thought processes and memory capabilities. Cartographers are focusing on lowering intrinsic load by tailoring maps to the skill level of the reader (Gilmartin, 1981; Blades & Spencer, 1986).

Cartographers and those interested in the implication of GIS in education are currently paying close attention to developments in the understanding of cognitive load within multimedia learning. Mayer and Moreno (2003) established three assumptions of the theory of multimedia learning. The dual-channel assumption stipulates that information being gathered by a learner falls into one or both of two working memory processing channels. The verbal channel processes auditory stimuli, while the visual channel handles visual stimuli such as pictures and text. The limited-capacity assumption is based on CLT and states that there is a limited amount of processing capacity within working memory. The active-processing assumption dictates that for any amount of learning to take place, there must be integration of information from the verbal and visual channels as well as prior knowledge found within long-term memory. They also offer scenarios of cognitive overload, or the exhausting of cognitive processing capabilities, that should be avoided when engaging in multimedia instructional development. The first type of overload occurs when one channel receives more information than it is able to process. The second type of overload occurs when both channels simultaneously receive more information than is possible to process. The third and fourth scenarios are similar in that they involve the incorporation of incidental overload into the process. Overload can occur when extraneous information not relevant to the task is presented alongside relevant information. This extraneous information can also appear in the form of confusion during a learning task due to poor instructional design technique. The fifth overload scenario occurs when information is required to be held in working memory while additional information is presented.

As stated by Sweller and others (1998, p.266), "a combination of the intensity of mental effort being expended by learners and the level of performance attained by the learners, constitutes the best estimator of instructional efficiency." There are two techniques commonly used to obtain measurements in the determination of instructional efficiency within CLT. Subjective techniques are based on the assumption that learners are able to recognize the amount of mental effort exerted during learning tasks and are able to give reliable reports. Subjective rating-scale measurements have proven to be the most promising technique for research in the context of CLT (Paas et al., 1994). They are based on the subject's ability to accurately determine the mental effort expended during testing. Task- and performance-based techniques use objective characteristics (e.g., number of elements under consideration) and performance levels (e.g., differential learning times, errors) to measure efficiency (Sweller et al., 1998).

Instructional efficiency can also be visualized through the use of a graph that combines cognitive load with performance measures (Paas & Van Merrienboer, 1994). This generally takes the form of a subjective measurement such as perceived task difficulty representing cognitive load and an objective measurement such as percent correct or reaction time representing performance. Raw measurements are converted to z-scores and plotted on a cross of axes. This method of efficiency analysis has proven to be the most widely used scale in CLT research due to its incorporation of proven measurement techniques and its ease of use (Sweller et al., 1998; Salden et al., 2004; Tuovinen & Paas, 2004; Lloyd & Bunch, 2010). High efficiency correlates with above average performance and below average effort, while low efficiency reflects low performance and a higher degree of effort (Bunch et al., 2008).

Pre- and post-testing of a students' spatial cognitive abilities can also be conducted as a means to ascertain the overall effectiveness of the incorporation of a GIS in the classroom. Wanner and Kerski (2000) believe that the types of geographic skills that are commonly examined in education-related research can be accurately assessed using pre- and post-testing. Under this methodology, the level of effectiveness of GIS as an instructional aide can be measured through the testing of students within control and test groups. Test groups are instructed with the use of GIS as an instructional aide while control groups are not.

Spatial Cognition and Thinking

In the field of geography, specific cognitive research on spatial abilities generally focuses on the concept and processes of 'spatial cognition', which is typically defined by the term 'mental map.' A mental, or cognitive map, is not a real map in the sense that it can be read verbatim, as can be done with hardcopy maps. Mental maps are percepts, or constructs, within our minds that enable us to store and analyze information in simple ways that often go unnoticed by the perceiver. Mental maps help us orient ourselves within our environment and provide us with a foundation from which to construct new spatial information in times of need (Tuan, 1975).

Cognitive mapping concerns the study of mental maps and, similarly, the ways in which our minds consciously and subconsciously acquire, learn, develop, use, and store spatial data within our everyday lives (Downs & Stea, 1973). Geographical research on cognitive mapping is traditionally concerned with the components of mental maps, the amount of information within those maps, and the learning and remembering of that information. Psychological research on cognitive mapping is traditionally based on the study of the cognitive processes that are taking place while thinking about spatial phenomena and the processes involved in the storage of that data. Although approaches may differ slightly, there is considerable overlap in the quest to understand how these data are stored and used. There have been many collaborative studies involving people with disabilities, such as vision impairments and mental retardation (Loomis et al., 1993; Golledge et al., 1991). Kitchin (1994) cites the universal need to understand how and why we behave the way we do in space, and the usefulness of the educational goals of improvements in wayfinding, orientation skills, and general map reading.

In one of the earlier studies in this vein, Flavell and others (1986) showed the ages at which students demonstrated abstract and spatial reasoning abilities. Those 15 years of age and older were able to demonstrate cognitive processes similar to adult processes. Children younger than 12 years of age showed a lack of these processes. Young adolescents between the ages of 12 and 14 demonstrated the ability to use abstract and spatial cognitive processes similar to adults (Flavell et al., 1986).

Cognitive studies performed by geographers include the effects of symbols and color (Nelson, 1995; Bunch, 1999; Bunch & Lloyd, 2000) and prior experience (Bunch, 2000; Lloyd & Bunch, 2003) on map-processing tasks. Nelson (1995) conducted research seeking to examine the ability of map readers to search for target colors among non-target colors on bivariate choropleth maps. Significant differences of reaction times were recorded for the variables of target color, similarity of target color, and the total number of objects on the map. Bunch (1999) conducted a study of twenty geography majors and twenty non-geography majors in order to gain a deeper understanding of the perceptual nature of color and visual-spatial processes during map searches. Maps depicting the state of South Carolina and its counties were searched for differences in the color (hue) or luminescence of target counties. Reaction times were found to be significantly impacted by each of the variables of color, luminescence, and distance between counties. In addition, he found that geographers had an advantage over non-geographers when searching for information on maps. In a study of two hundred forty-five young adolescents and adults, Bunch (2000) looked at the impact of age on the ability to understand the map-reading tasks of scale and information integration. The integration methods used stemmed directly from the ways in which GIS maps can be manipulated: through changes in scale, positioning, and layering. Subjects utilized a GIS to move between maps of differing scales or to access maps depicting sets of informative data. Young adolescents experienced more difficulties and recorded significantly higher errors than adults when processing spatial relationships such as city location, direction, and distance within the map. Bunch calls for additional cognitive research on the spatial abilities of young adolescents, suggesting the testing of fundamental map tasks. In agreement with Downs and Liben (1991), Bunch concludes that the type of task and the abilities of the subject are an important consideration in GIS design and teaching strategies. These findings illustrate the value and potential impact of future research focusing the attention of GIS incorporation into the secondary educational system, thus targeting young adolescents who have the minimal cognitive abilities required to interpret spatial analyses. These recent geography-centered research studies in spatial cognition indicate that geographers are aware that the order and complexity with which new information is presented can be directly influenced by the teacher through the manipulation of instructional design, thereby reducing extraneous and increasing germane load.

Map Overlay

Map overlay allows for the splitting of features that either fully or partially overlap other features. Geographers place a great importance in this ability as it represents a process for direct manipulation and comparison of areas that differ from adjacent areas in as little as one attribute. Map overlay requires that an individual store spatial objects in memory and perform specific mental operations on those objects based upon geographic concepts. The three basic functions of the map overlay process tested are intersect, union, and erase. The intersect function is when spatially alike areas of two or more features are combined into one feature, representing the spatially alike area and attributes (information) of each feature (Figure 2). The union function is when areas of two or more features are combined into one feature representing the area of a common attribute of each feature (Figure 3). The erase function is when spatially alike areas of two or more features are deleted from each feature resulting in the preservation of areas not common to all features (Figure 4).

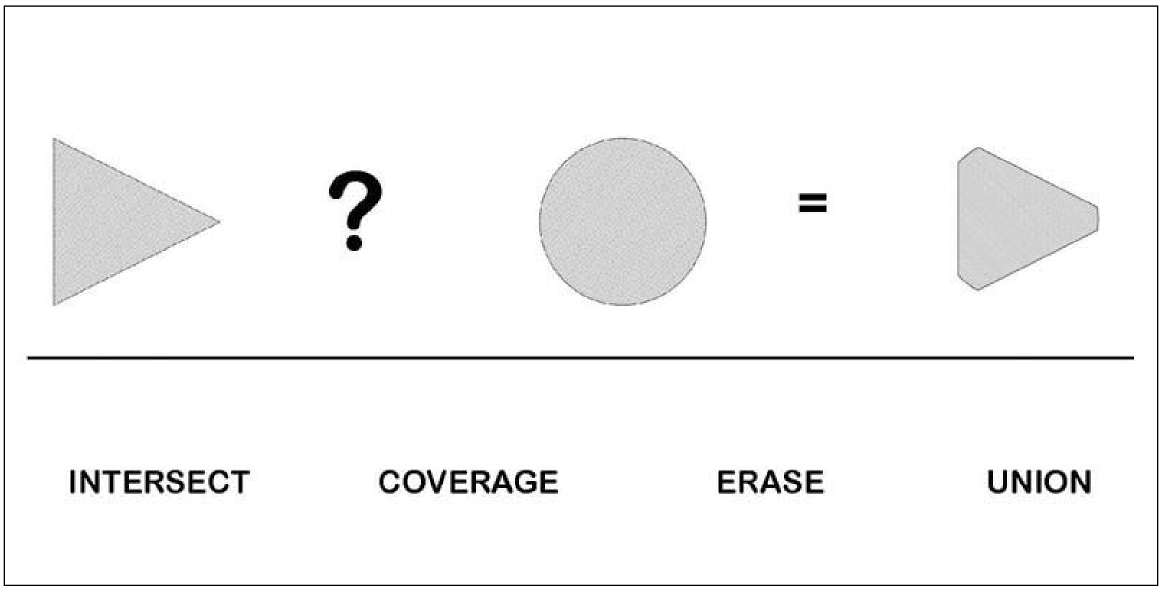


Figure 2. Example of intersect function in relation to methodological structure.

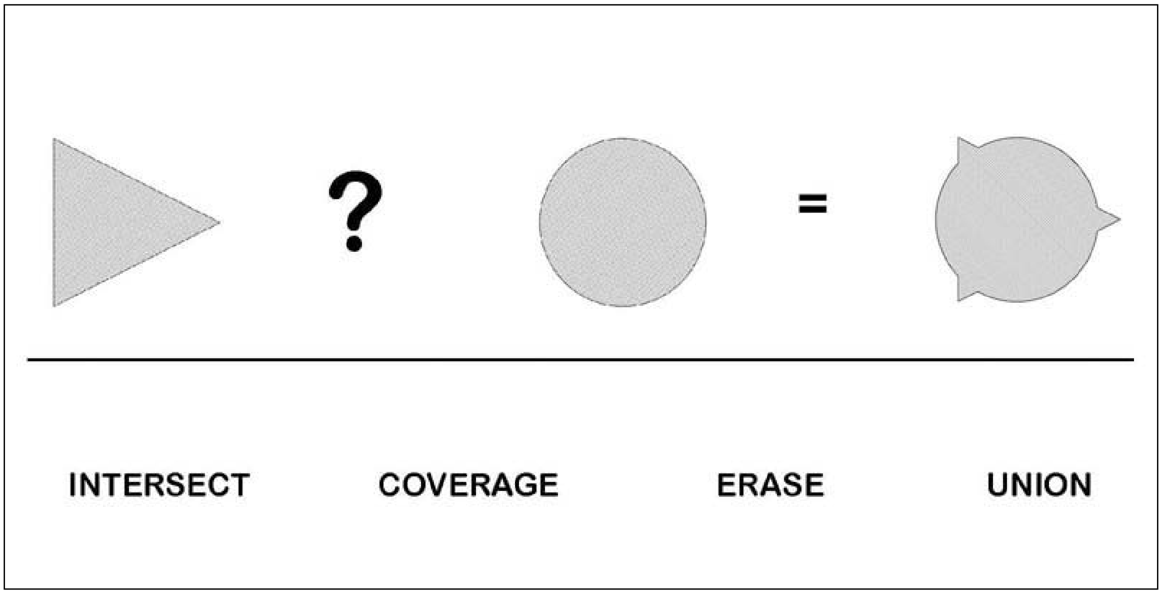


Figure 3. Example of union function in relation to methodological structure.

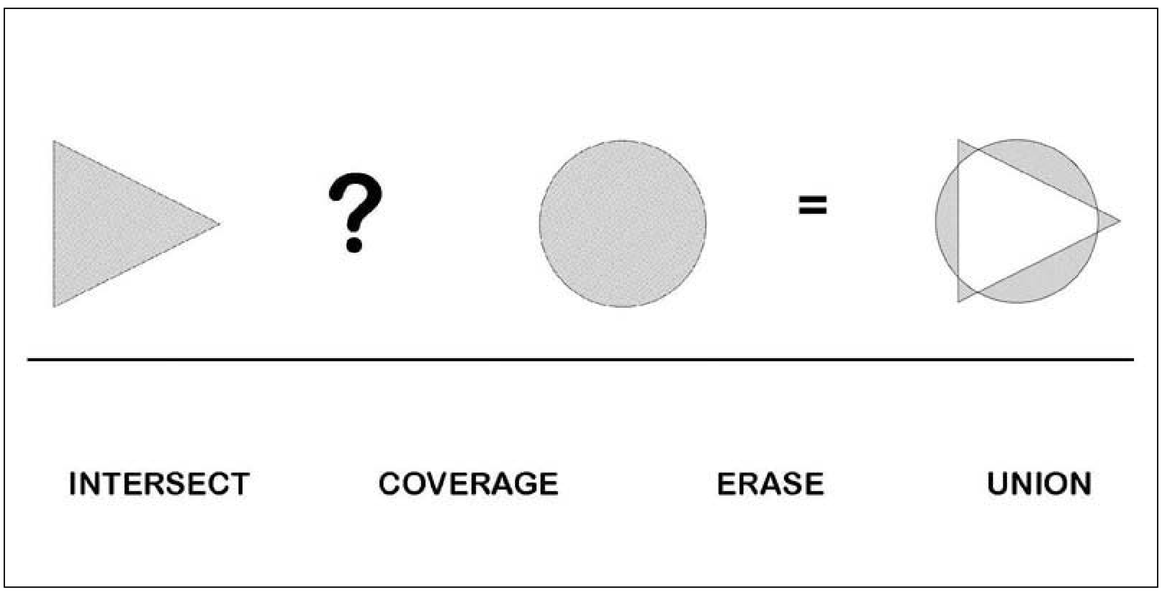


Figure 4. Example of erase function in relation to methodological structure.

Albert and Golledge (1999) researched the ability of undergraduate students to utilize the map overlay concept given map input layers, map output layers, and logical operators. Students completed three tests in which they were asked to accurately complete map overlay operations which were missing one of three basic components: input layers, logical operator, or output layer. Accuracy was the performance measurement utilized for each of the three tests. A significant difference of test type was observed between missing operators and output layer as well as between input layers and output layer with less accuracy being demonstrated at determining the correct output layer in each case. Logical operators included ‘or’, ‘and’, ‘xor’, and ‘not’ corresponding to the functions of union, intersect, and erase respectively. The ‘not’ operator was a specific case of the erase function in which the order of input layers was important to consider. Significantly better performances were observed for both ‘or’ and ‘xor’operators above ‘and’ and ‘not’ operators. It was also noted that no significant difference was observed dependent upon the complexity of the polygons used within the operations. Results also showed no significant differences between students having prior experience with a GIS and those with no experience or males and females on tasks inherent to the map overlay concept.

Battersby, Golledge, and Marsh (2006) tested for incidental knowledge of the map overlay concept among middle school, high school, and undergraduate students. Students were first given a test in which questions depicted two maps that were to be mentally overlaid in order to determine the area corresponding to specific criteria depicted on each map. For example, a map depicting crops and a map depicting soil types would need to be used to determine the area meeting the requirements of the question; corn and sandy soil. It was observed that a significantly fewer number of middle school students than high school or undergraduate students used map overlay to answer each question. With respect to map overlay accuracy, significant differences were observed between all three groups with higher performance following increasing age of student. A second test introducing the logical operators of ‘or’, ‘and’, and ‘not’ was administered to ascertain any differences in the basic understanding of unique map overlay functions. Students were presented with questions that contained two overlapping circles and an operator. They were told to shade the portion(s) of the circles corresponding to the operator function. High school and undergraduate students performed significantly better than middle school students across all operators. No significant differences between operators were observed within any age group. Their findings suggest that high school (adolescent) and undergraduate (adult) students can be classified together in their ability to understand the map overlay concept. This knowledge was found to be incidental to these groups, having scored expertly without any formal instruction prior to testing. Middle school aged students (young adolescents), however, scored poorly on the use and accuracy of this spatial concept, illustrating a lack of incidental knowledge.

It is postulated that the underlying spatial concept of map overlay can be learned prior to the adolescent stage through intentional learning activities (Flavell, 2006). It is also suggested that GIS could be used as an educational tool to help learn the basics of the map overlay process (Bunch, 2000; Kerski, 2003). The research findings of the previous studies suggest that young adolescents do not exhibit the cognitive ability to perform complex spatial tasks at a mature level, especially in the absence of instruction. Flavell and others (1986) pinpointed young adolescents as prime candidates for instructional testing scenarios when they declared that this age group had developed abstract and spatial reasoning abilities similar to adults, albeit not honed. The framework for this study is contained within the intersection of the three academic disciplines from which it is constructed. The fundamental goal is to determine if a complex spatial concept such as map overlay can be effectively learned through the utilization of an instructional technique based within the foundations of geographic education, educational psychology, and spatial cognition.

CHAPTER III

METHODOLOGY

Design

The experimental design of Albert and Golledge (1999) was adopted to provide the foundation for this study. This study focuses on the ability of students to understand and learn the concepts of map overlay functions. Inherent to each map overlay function is the mental ability to manipulate input layers into output layers and vice versa. This study is also interested in the demonstration of students' ability to perform mental manipulations specific to the map overlay functions. The use of a map overlay function can be conceptualized as a linear process following a sequential order of operations where an input layer is overlaid and operated with another input layer resulting in an output layer. This study refers to the changing location of a missing element within this sequential process as spatial cognitive manipulation. Similar to Albert and Golledge's (1999) design, each test question contains three of the four elements that constitute a complete map overlay operation, and a question mark, '?', symbolizing the missing element that completes each operation correctly. The ability to perform spatial cognitive manipulations is measured by altering the location of the '?' to each of the four elements. Beneath each question is a list of four possible solutions to the operation. This experimental design allows for the testing of knowledge acquisition of each of the map overlay functions and the manipulation of each of the four elements that make up map overlay operations

The instructional approach adopted by this study is very similar to that of part-task practice described in the 4C/ID model by Van Merrienboer (1997). The map overlay concept consists of three functions that are taught and tested through repetition independent of one another. Each of these functions is then dissected and instructed according to the four different spatial cognitive manipulations. The following describes additional details of the experimental design. Included are detailed descriptions of the instruction and testing stimuli, the subjects who participated in the experiment, and the procedure for data collection. Several testable hypotheses are also offered.

Instruction and Testing Stimuli

The material presented during both the instruction and testing phases of this study are identical in their format. Albert and Golledge (1999) identified three different processes that may take place when working with map overlays: 1) the selection of the appropriate function to achieve the desired result, 2) the verification that a map overlay process has taken place correctly, and 3) the identification of appropriate objects whose overlay results in a specific outcome. Figures of map overlay procedures are presented following the generic format of ‘A+B=C’, where ‘A’ and ‘B’ are map overlay inputs, ‘+’ is the map overlay function, and ‘C’ is the map overlay output. The input elements (A1 and A2) consist of simple shapes that can be overlaid in any manner, barring any rotation. The map overlay function element (B) consists of the name of the function performed on the input layers. The output element (C) is a shape representing the appropriate outcome of the intended map overlay function. Specifically, the resulting questions take on the format, ‘A1 B A2 = C’. Figure 5 illustrates an example where the first input must be solved using the given function (in this case erase), the second input, and the output. This example focuses on the ability of the subject to select the appropriate shape whose combination with another shape results in the specified output while adhering to the operational rule of the given map overlay function. Figure 6 illustrates an example where the function must be solved using the given first and second inputs and the output. This example determines the ability of the subject to identify the appropriate function to solve the operation. Figure 7 illustrates an example where the second input must be solved using the given first input, the function, and the output. Similar to Figure 5 in conceptual framework, this example simply tests the ability of the subject to perform the necessary operation given the conditions of the question in a different order than when solving for the first input. Figure 8 illustrates an example where the output must be solved using the given first and second inputs and the function. This example confirms the ability of the subject to properly use a specific function on existing shapes to achieve the desired outcome.

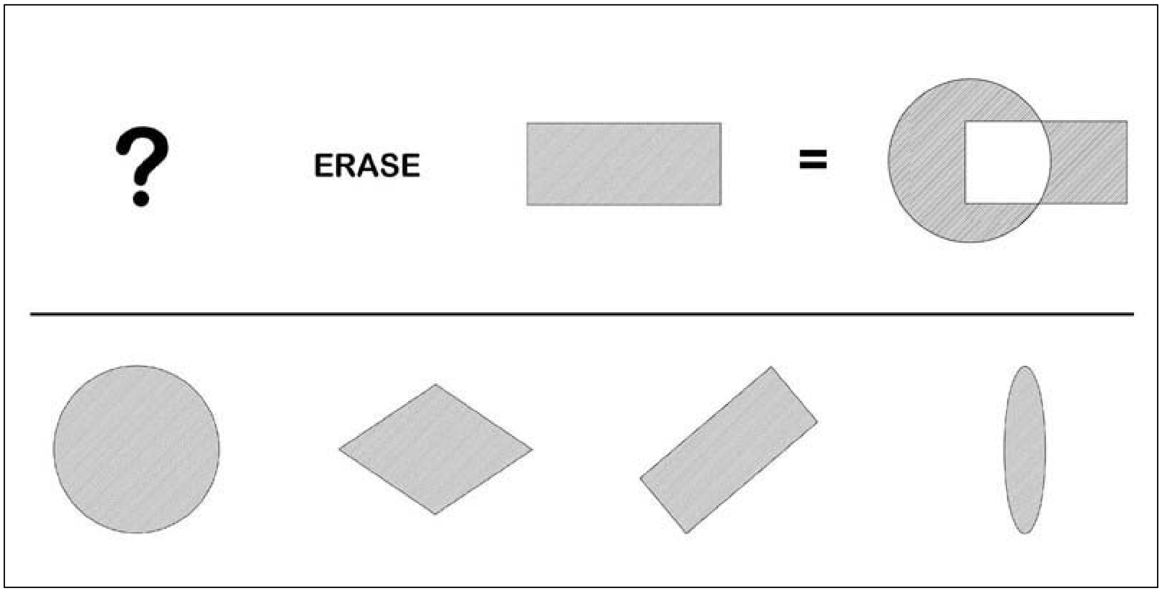


Figure 5. Example of “first input element / A1” test question.

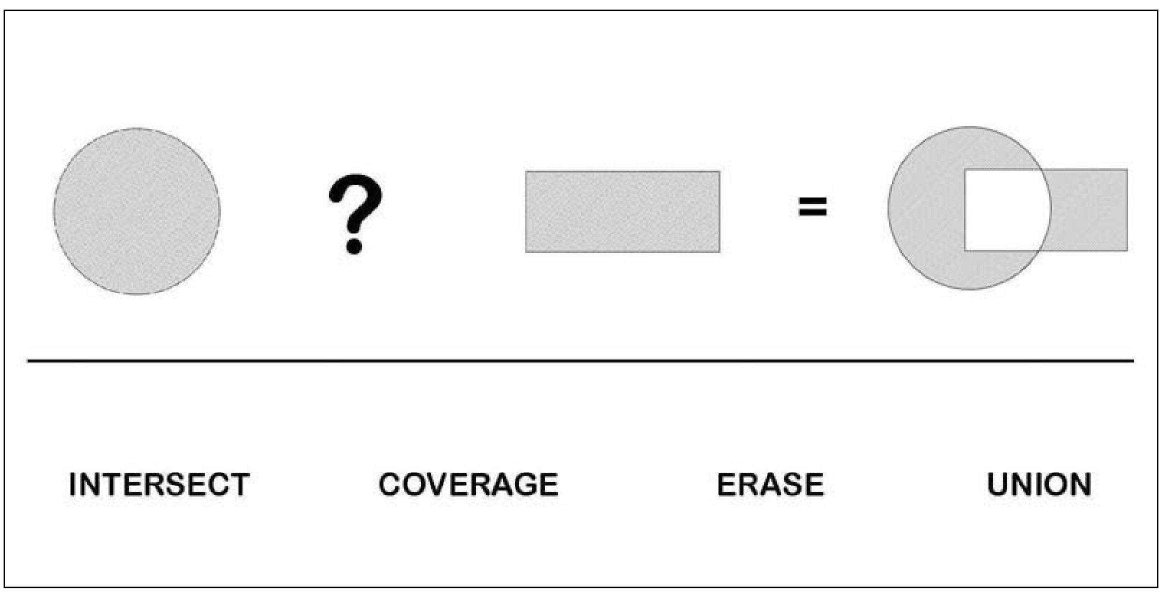


Figure 6. Example of “function element / B” test question.

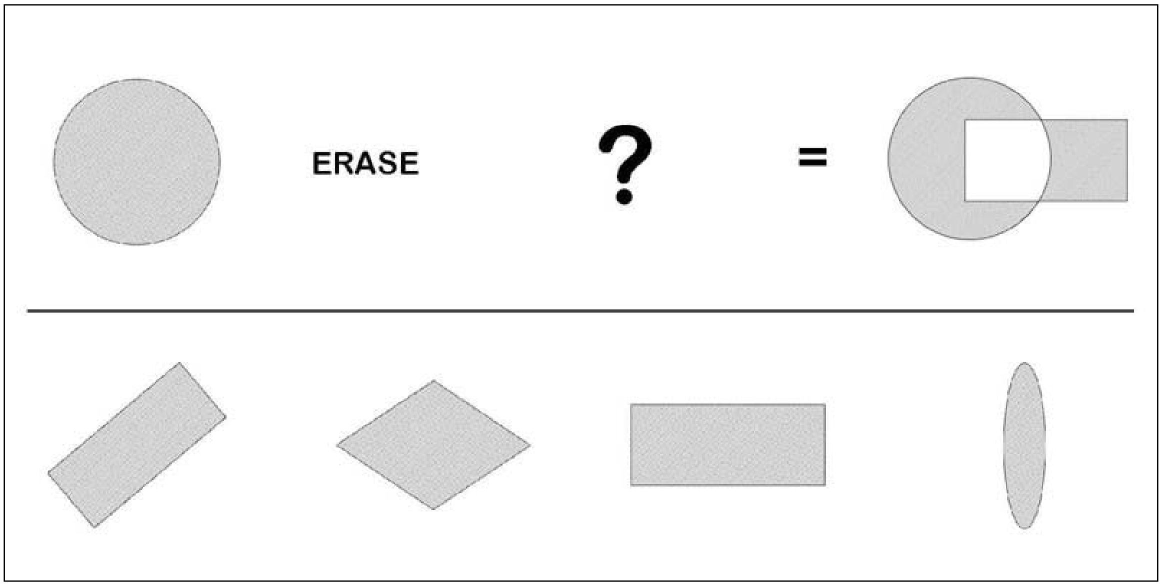


Figure 7. Example of “second input element / A2” test question.

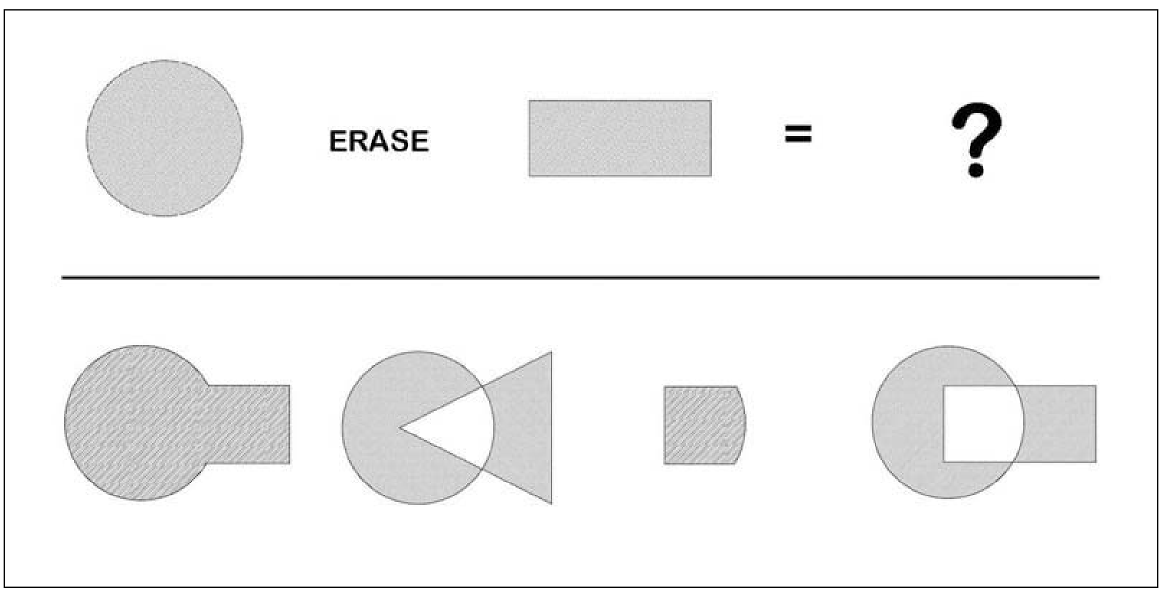


Figure 8. Example of “output element / C” test question.

Subjects

There were 203 subjects tested during this study (Table 2). The test, control, and expert group each consisted of a minimum 60 subjects. This comprised a minimum of 30 males and 30 females tested in each group. Middle school students between the ages of 12 and 14 years made up the test and control groups of this study, and represent subjects with little to no incidental knowledge of the map overlay concept. These young adolescent students were recruited from Saint Pius X Catholic School in Greensboro, North Carolina. Assent of the participants was requested by the researcher in order to minimize any potential obligation to the school perceived by the students (Appendix A). This study also required the completion of a parental consent form describing the testing conditions and procedures of the study (Appendix B). The first 60 males and the first 60 females who returned both consent and assent forms were accepted into the study. These forms were collected by the students' school teachers on a daily basis and resulted in an additional handful of students for both the control and test groups. The expert group was made up of undergraduate students from the University of North Carolina at Greensboro. Students were chosen from introductory level Earth Science courses, and represent subjects with incidental knowledge of the map overlay concept. Students were compensated for participation with a ten percent extra credit bonus on an exam grade (Table 2).

Table 2. Number of subjects tested.

		SEX	
		Male	***Female***
GROUP	***Test (young adolescents)***	31	32
	Control (young adolescents)	33	31
	Expert (adults)	30	46

Test Materials and Data Collection

The tests consisted of 120 questions drawn from a pool of 720 questions and presented in random sequence via a computerized testing application; ten questions each of all combinations of map overlay function and spatial cognitive manipulation. The development of questions combining both of these tasks simulates the many ways in which questions requiring map overlay abilities are encountered in real-world experiences. Figures 5, 6, 7, and 8 represent test questions fulfilling the combination requirements of Erase/A1, Erase/B, Erase/A2, and Erase/C respectively. Similar questions were created fulfilling the requirements of the Intersect and Union map overlay functions being combined with each of the four representative spatial manipulations. These combinations supplied a sufficient number of responses for later analysis of each of the variables of map overlay function and spatial cognitive manipulation (Table 3).

All tests consisted of a set of unique questions which were not reused on any other tests to ensure that no map overlay question was repeated or seen twice by any of the subjects.

Table 3. Experimental Design. Number of questions per map overlay function and spatial cognitive manipulation task.

		Spatial Cognitive Manipulation				
		A1	***A2***	***B***	***C***	*Total*
Map Overlay Function	***Intersect***	10	10	10	10	40
	Union	10	10	10	10	40
	Erase	10	10	10	10	40
	Total	30	30	30	30	120

Procedure

A computerized testing application was developed to present test questions and to collect responses from subjects. The experiment was presented on a laptop computer screen that displayed each trial or question in random order. The test, control, and expert groups were each exposed to a unique set of instruction and testing scenarios. The following is a detailed description of the procedures for each of the three experimental groups.

The instruction and testing of the test group occurred during a regularly scheduled science or social studies class period. The multimedia center of the middle school was reserved as the study environment and testing center. Test group subjects were divided into subgroups of no more than ten subjects. This subgroup size was determined by the limited availability of laptop computers and the size of the multimedia center. Subjects received approximately 30 minutes of for both the instruction and testing sessions.

A pre-test was administered to serve as a baseline for future analysis for all experimental groups. The pre-test constituted the first epoch of instruction and testing that would occur throughout the course of the study. The difference between the pre-test and all subsequent tests was the amount and type of instruction given prior to the computerized testing. Pre-test instruction was minimal and only given to ensure that each subject had enough understanding of the subject material to complete the pre-test. The pre-test instruction consisted of details on the definition of each map overlay function supplemented by a corresponding pictorial illustration. For example, the following definitions were read to each group: "The union function is when areas of two or more features are combined into one feature representing the area of a common attribute of each feature found within." "The erase function is when spatially alike areas of two or more features are deleted from each feature resulting in the preservation of areas not common to all features." "The intersect function is when spatially alike areas of two or more features are combined into one feature representing the spatially alike area and attributes of each feature found within." Immediately following instruction on each definition, illustrations were incrementally drawn on a white board to visually reinforce each concept. The test group received recurrent instruction and testing on a weekly basis for six weeks. Recurrent sessions with the test group were conducted in hopes of showing a point of diminishing return. The instructional process of subsequent testing sessions (epochs) differed from that of the pre-test. The instruction given to the test group during subsequent epochs consisted of the aforementioned map overlay function definitions along with a series of map overlay illustrations shown repetitively on a computer screen in the front of the testing center (Appendix C). The addition of these repetitive illustrations during weekly instruction constituted the main difference between the instruction given to the test group and all other groups.

Upon the completion of the instructional portion of each session, subjects initiated the computerized testing application. Prior to beginning the experimental portion of the test, subjects were required to record information that would identify them as the test-taker (Figure 9). Due to the fact that test group subjects were under the age of 18 and to ensure confidentiality, each subject was given a unique identification (sequence) number to identify them in a database and associate all test result data. The unique sequence number (Figure 10) and the sex (Figure 11) of the subject were recorded by the computer application. A confirmation screen was also presented to the subject to ensure all participant information was correct (Figure 12).

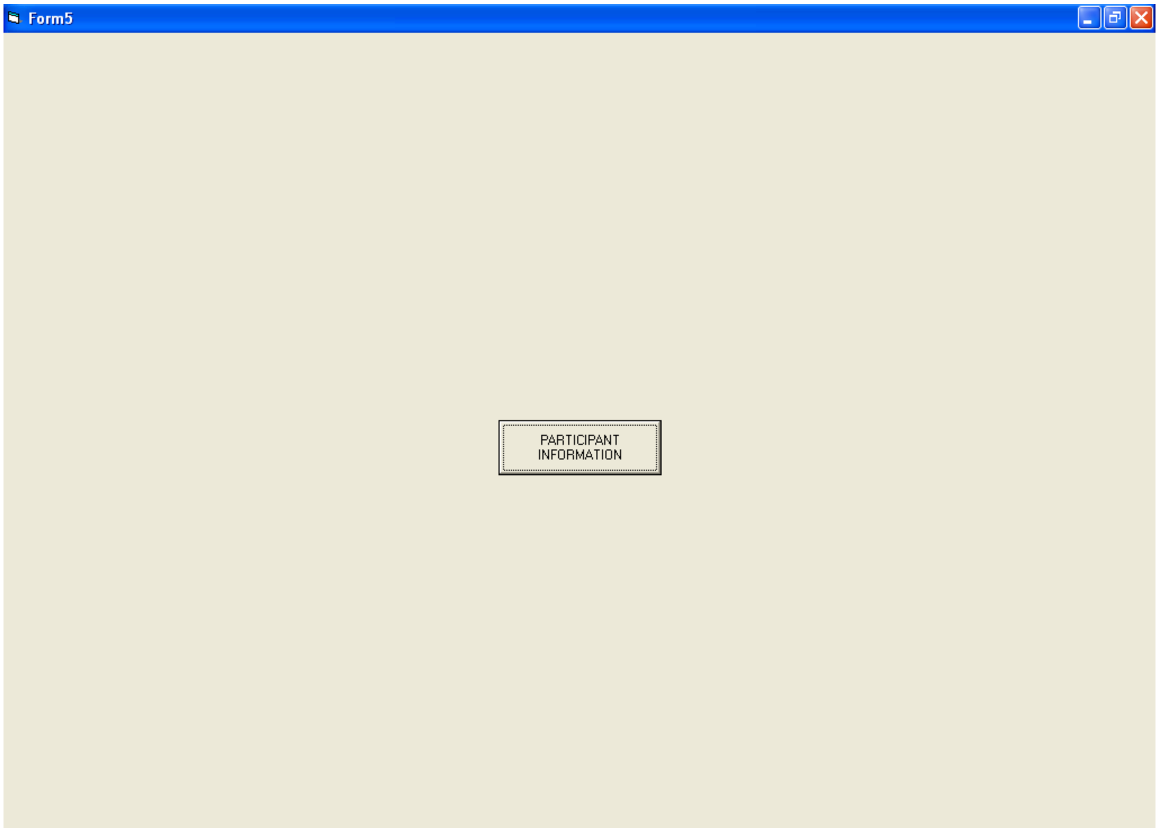


Figure 9. Introductory screen of computerized testing application.

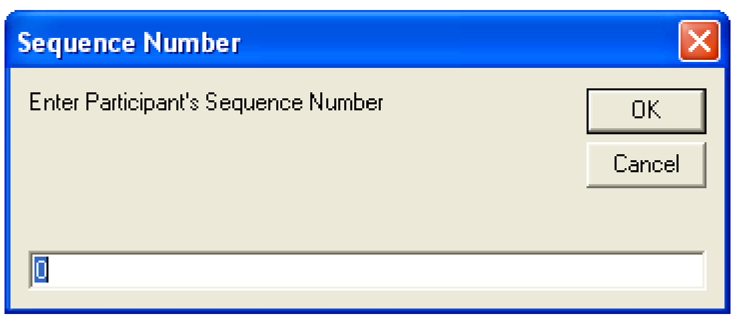


Figure 10. Application form requiring subject's unique sequence (identification) number.

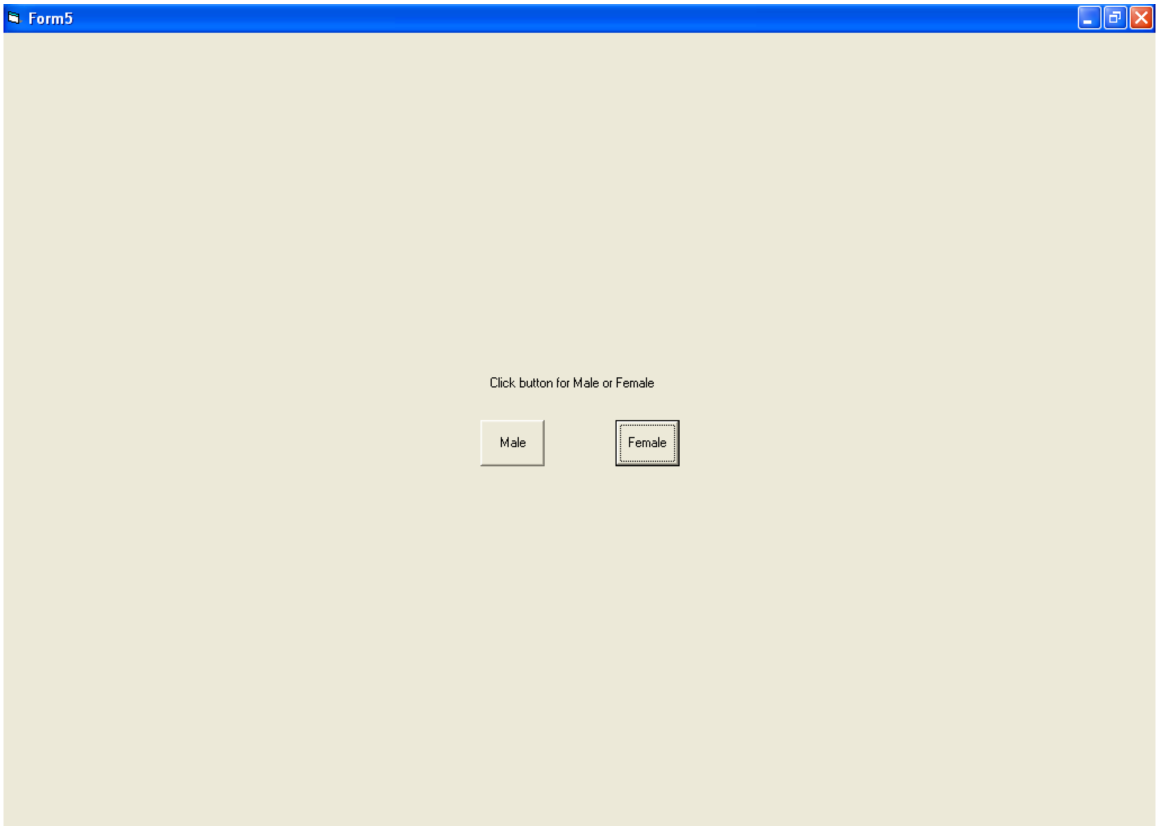


Figure 11. Application form requiring subject's sex.

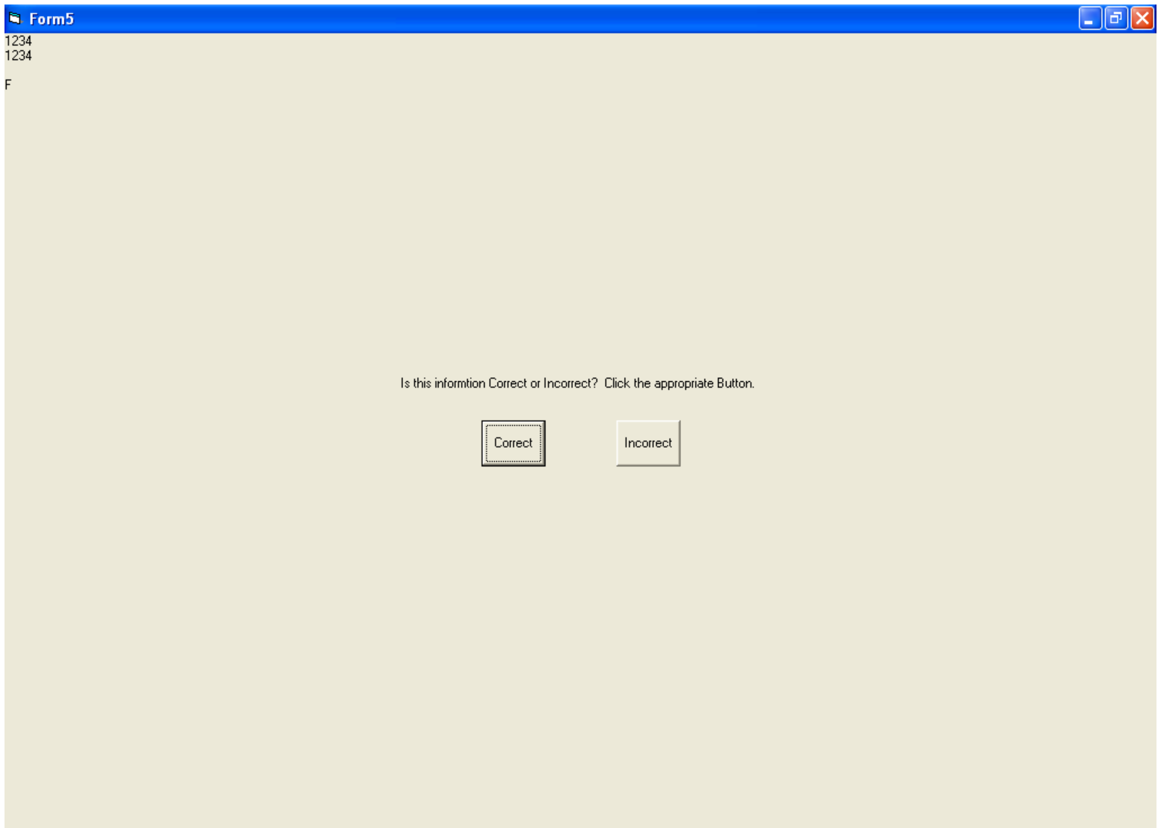


Figure 12. Application form requiring confirmation of subject's identification information.

After confirming the identification information, subjects began a short practice test aimed at demonstrating the controls of the experiment, while avoiding the concepts being tested (Figure 13). Twelve mathematical questions were created by substituting numbers for the map overlay elements (A1, A2, C) and substituting the addition symbol '+' for the function element (B). Figures 14, 15, 16, and 17 are examples of practice questions that act as surrogates for test questions requiring the resolution of missing A1, B, A2, and C map overlay elements respectively. These easy-to-solve addition questions familiarized the subjects with the format of the test questions and the process of clicking the appropriate answer on the computer screen. The subject selects an answer by clicking on one of the four buttons directly beneath the object representing the appropriate solution to the question (Figure 18). In this example, the solution to the ‘1+2=?’ question is ‘3’ and requires the subject to click on the button labeled ‘C’ beneath the number ‘3’. Subjects were required to answer all twelve practice test questions correctly before being allowed to begin the experimental test. If any practice questions were answered incorrectly, the subject would be directed to repeat the practice test (Figure 19); otherwise they were allowed to begin the experimental test (Figure 20).

Figure 13. Application form introducing practice test.

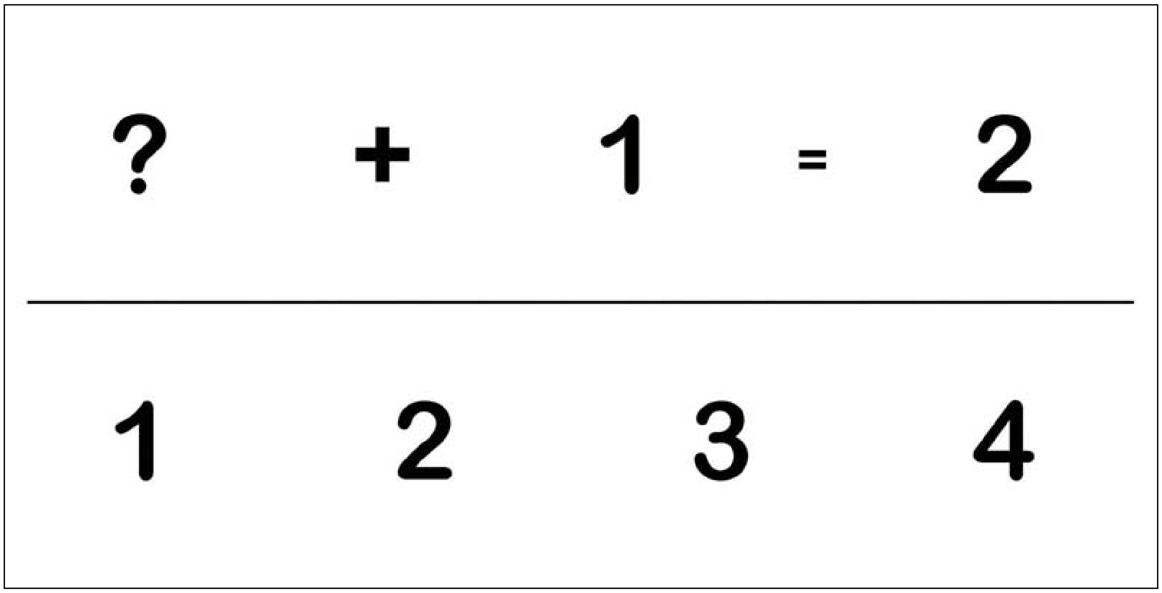


Figure 14. Example of “first input element / A1” practice question.

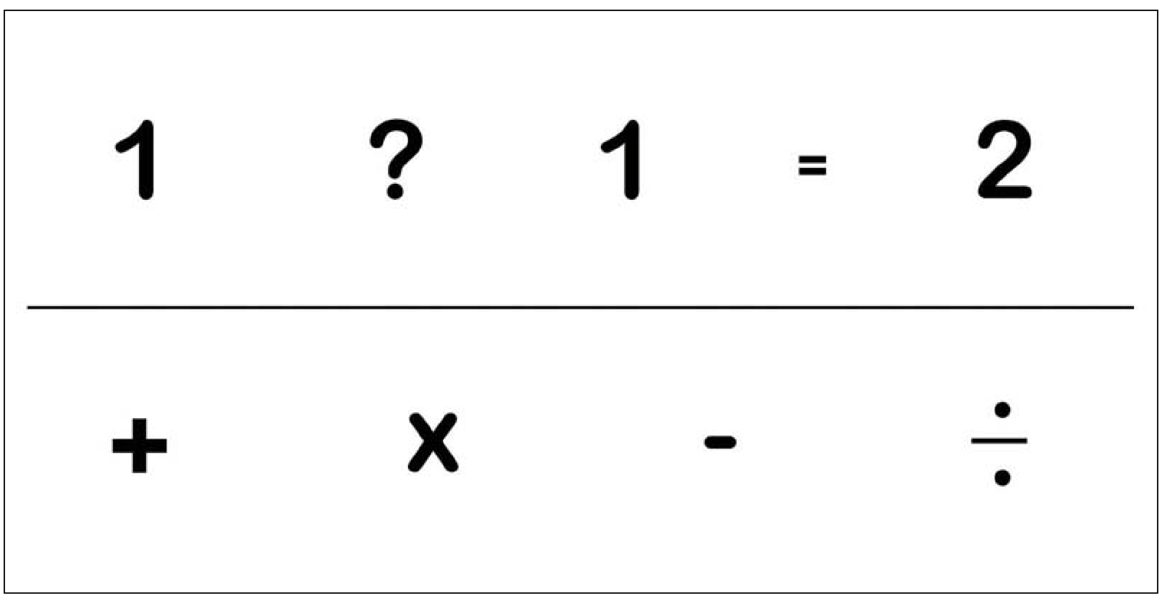


Figure 15. Example of “function element / B” practice question.

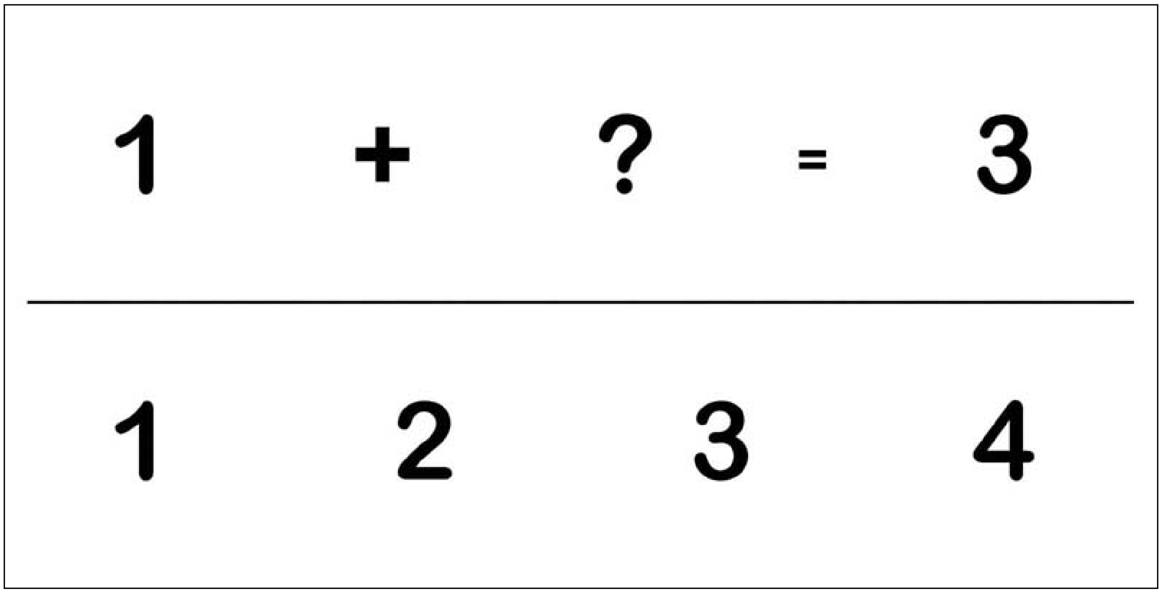


Figure 16. Example of “second input element / A2” practice question.

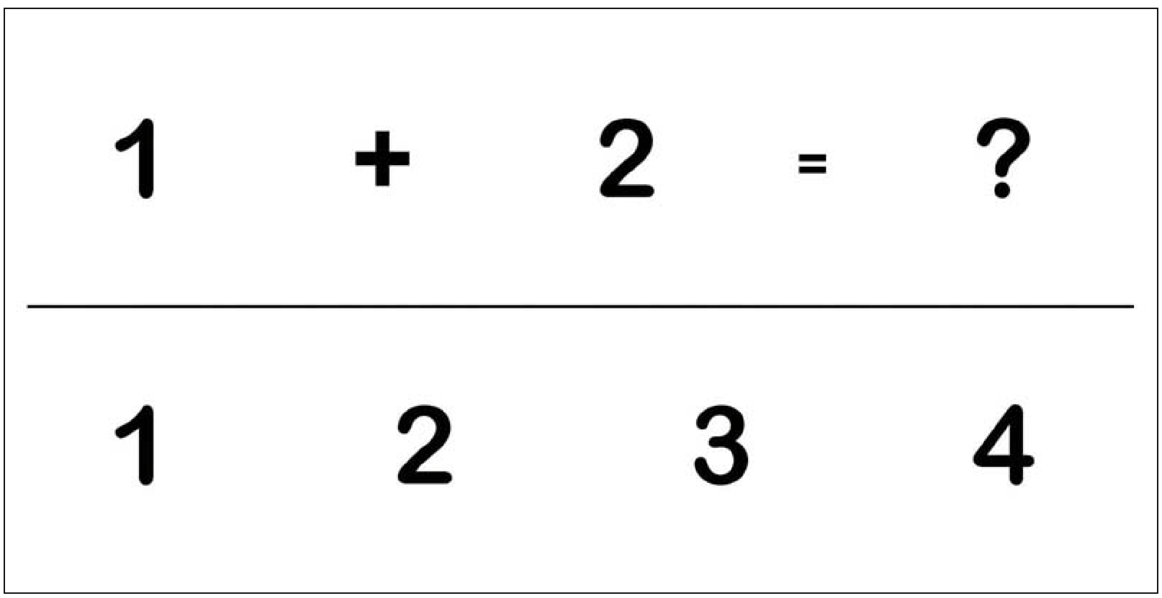


Figure 17. Example of “output element / C” practice question.

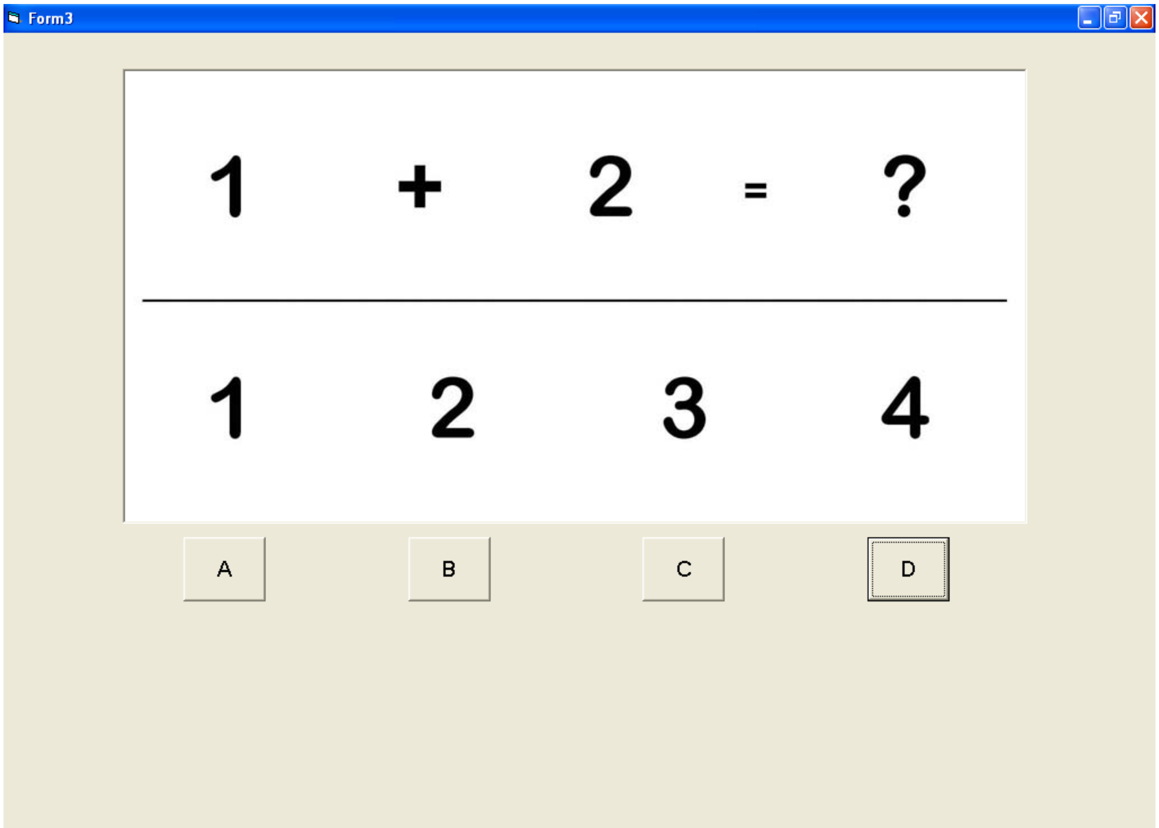


Figure 18. Example of practice test question.

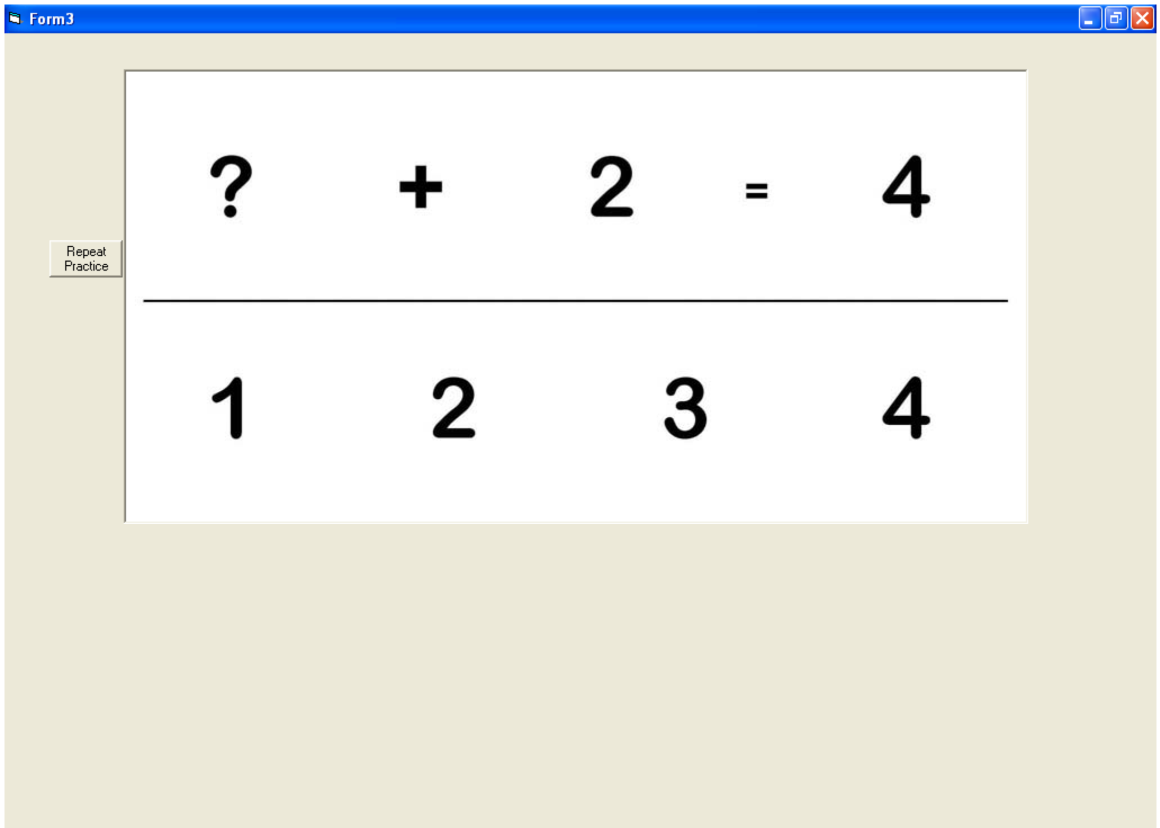


Figure 19. Application form requiring subject to repeat the practice test.

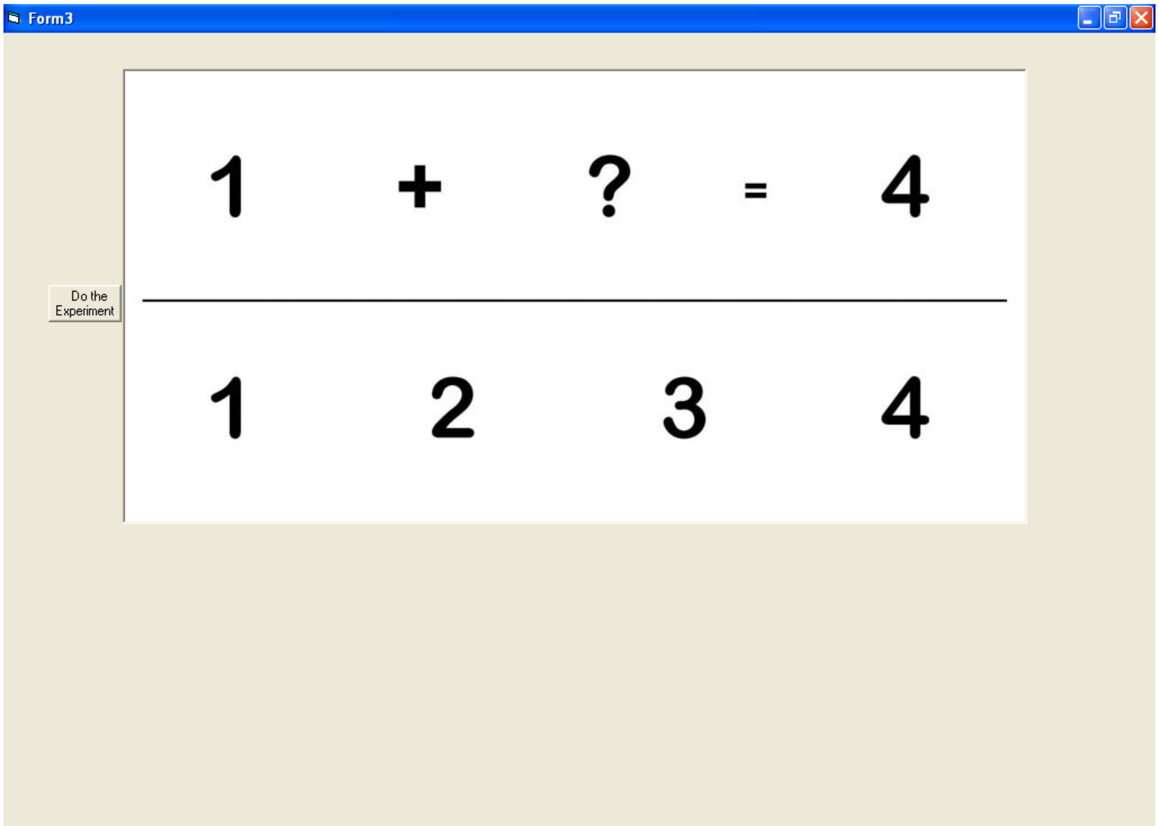


Figure 20. Application form confirming completion of practice test.

After subjects had successfully completed the practice test, they were prompted to begin the experimental test (Figure 21). Similar to the practice questions, a map overlay formula appeared across the top of the computer screen. Each of the map overlay components were depicted in the 'A1 B A2 = C' format, and the missing component was represented by the '?' symbol. Across the bottom of the computer screen were four objects representing the possible missing component that correctly completed each map overlay formula. Similar to the practice test, the subject selected an answer by clicking on one of the four buttons located directly beneath the object representing the solution to the question (Figure 22). In this example, the first input object is missing from the formula. Understanding that the question involves the union map overlay function, the solution to the formula requires the use of the third object from the left along the bottom of the computer screen. This object is associated with the ‘C’ button, which is the correct answer. Upon the selection of an answer, the computer application records the chosen answer, whether that answer was correct or incorrect, the time in milliseconds between the appearance of the question and the selection of the answer, the map overlay function and spatial cognitive manipulation represented by the question, and the unique identification number and sex of the subject. When an answer is selected by the subject, the next question immediately appears on the computer screen, and the process repeats until all questions are answered (Figure 23). At the end of the test, subjects are directed to save the results of their test and close the application (Figure 24). All information collected by the application is saved into a tab-delimited text file for incorporation into a relational database for later analysis.

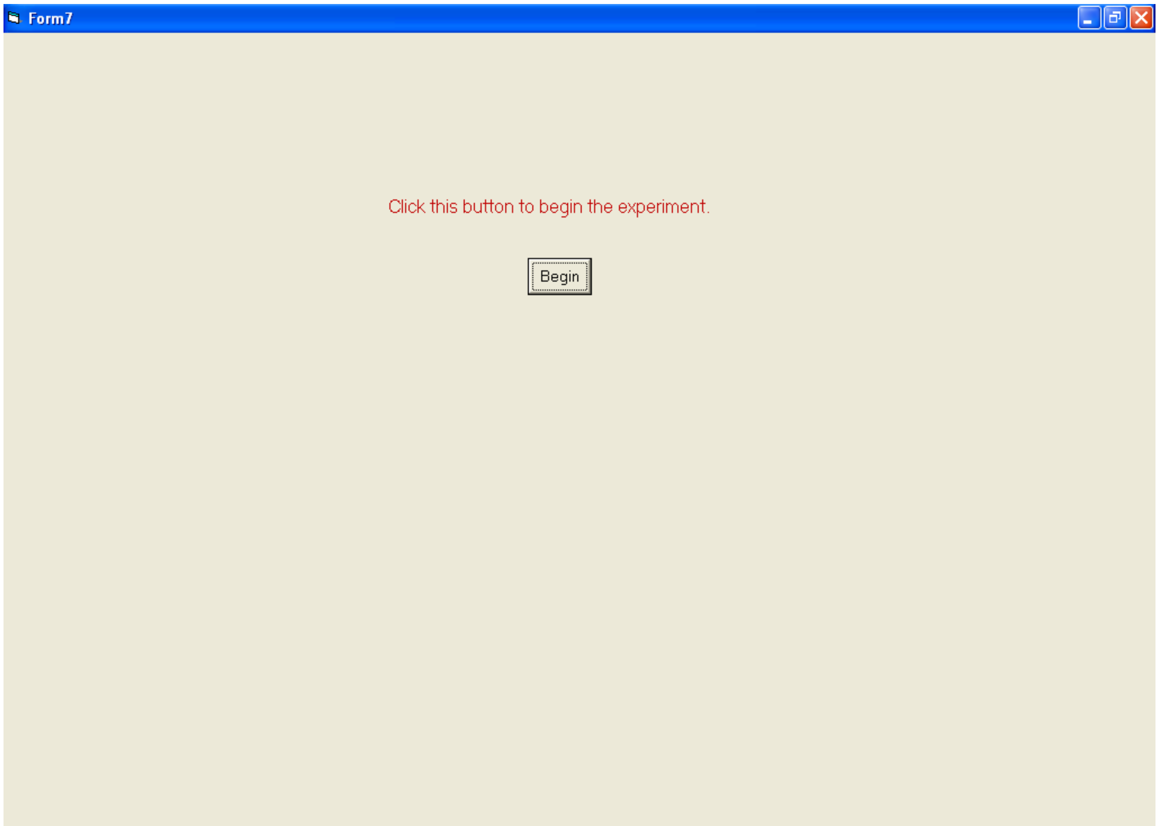


Figure 21. Application form prompting beginning of experimental test.

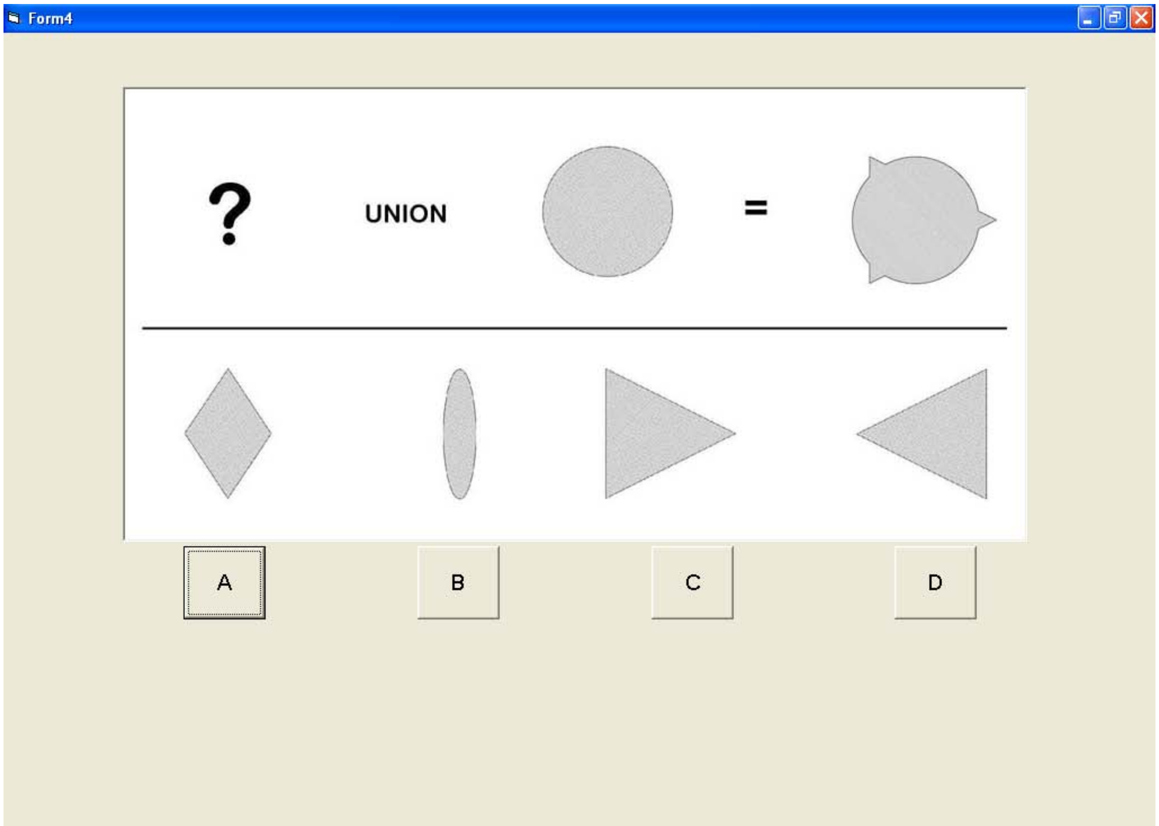


Figure 22. Example of experimental test question.

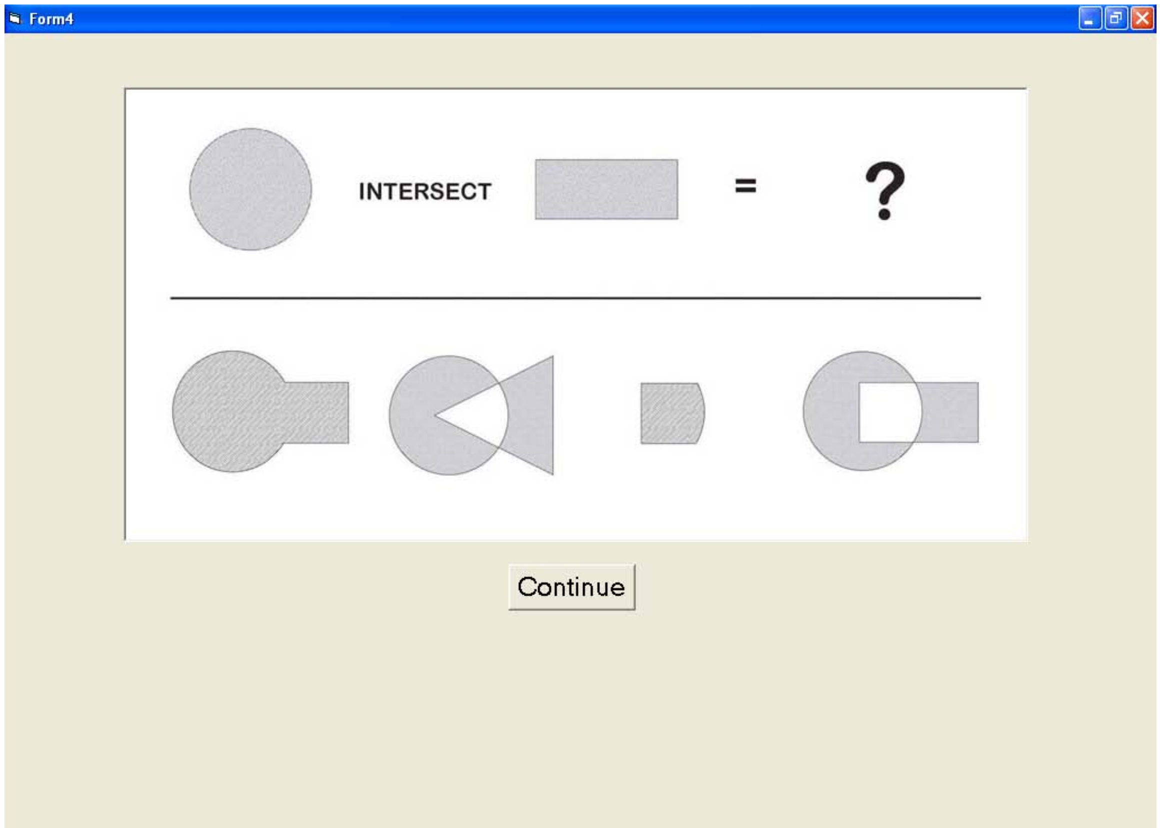


Figure 23. Application form confirming the completion of the final experimental test question.

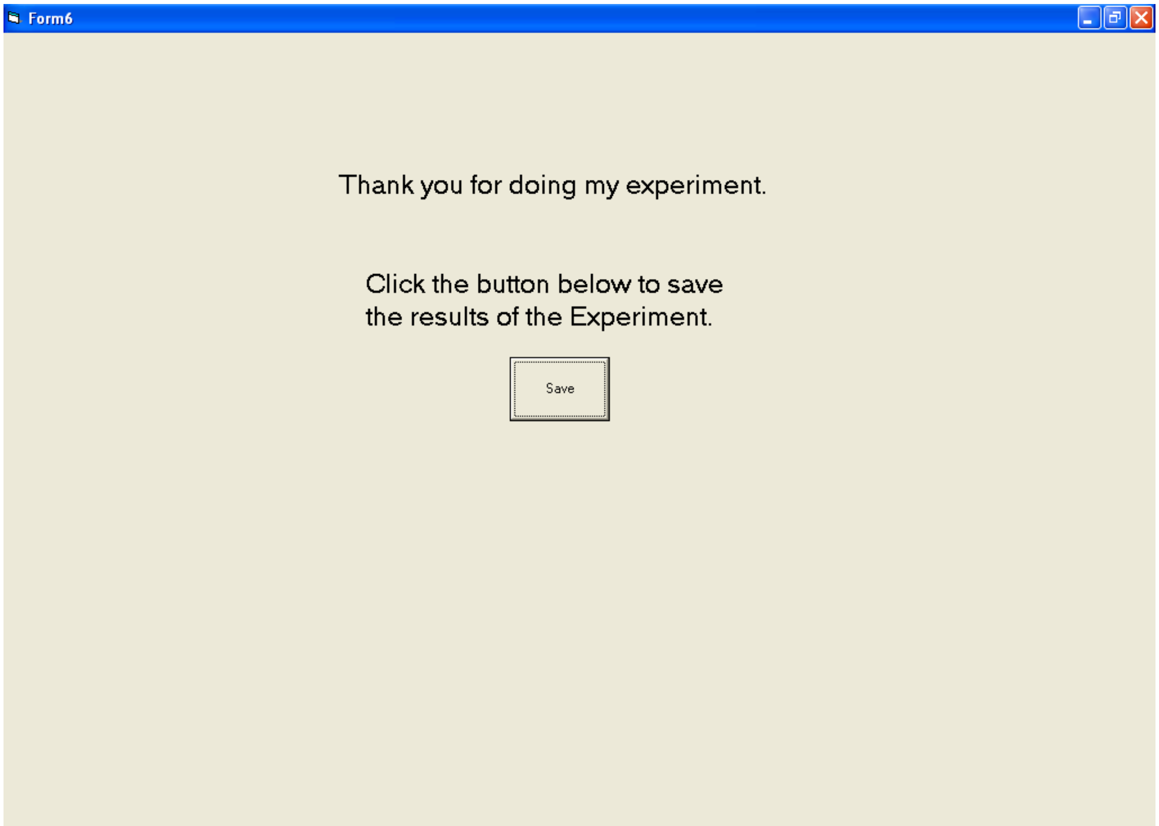


Figure 24. Application form confirming the save of test data and close of application.

Test group subjects repeated this instruction and testing scenario on a weekly basis for six weeks. The sixth epoch was designated as the post-test of the study. The format and conditions of the post-test were identical to those of epochs 2 through 5. The designation of this final epoch as the post-test was done to signify the corresponding results as those of the final epoch of computerized testing during the study. These results would later be analyzed against those of the control group tested during the same week (week 6). Any diminishing point of performance by the test group was to be analyzed against both the control and expert groups.

The test group was given a pencil and paper test at the conclusion of the computerized testing during week 6. This test consisted of a single "real-world" question designed to test each student's ability to mentally perform multiple complex map overlay operations. The question required the use of four map figures and three criteria that forced the use of each map overlay function to be performed (Appendix 4). After answering the question, students were asked to rate the level of mental difficulty they experienced while answering the question. This self-reported level of difficulty served as a subjective measurement that could be used in future instructional efficiency analysis. A scale ranging from 1 to 9 was used. Values corresponded to the following levels of difficulty: 1-extremely easy, 2-very easy, 3-moderately easy, 4-slightly easy, 5-neutral, 6-slightly hard, 7-moderately hard, 8-very hard, and 9-extremely hard.

The control group also received instruction and testing in the multimedia center of the middle school during a regularly scheduled science or social studies class period. For the same reasons described earlier, control group subjects were also divided into subgroups of no more than ten subjects. The control group received the pre-test instruction and testing under the same format and conditions as the test group. These pre-test results would later be analyzed along with the pre-test results of the other study groups. Upon completion of the pre-test, the control group received regular classroom instruction only, and did not undergo weekly instruction and testing consistent with or administered by this study. Regular classroom instruction consisted of materials presented and discussed solely by the middle school teachers as dictated by the school's curriculum. The control group also received a post-test during the sixth week of the study. The format and conditions of this post-test were identical to those experienced by the test group. The need for a control group post-test is two-fold. Both test and control groups continued to receive regular classroom instruction throughout the study. A post-test comparison between the groups served to balance any knowledge gained by students during traditional classroom instruction. Cherney (2008) emphasized that the use of a control group post-test will also rule out the possibility that any gains or differences are due to merely retaking the test. At the conclusion of the post-test, the control group was required to answer the same "real-world" question as the test group. Subjects also recorded the level of mental difficulty they experienced while answering the question by using the same scale ranging from 1 to 9.

The expert group received instruction and testing in an available classroom within the University's Department of Geography. These undergraduate students were also divided into subgroups of no more than ten subjects. Members of the expert group received only the pre-test. No additional testing or questioning was considered necessary since adults have been shown to possess incidental knowledge of the map overlay concept and any manipulations thereof (Albert & Golledge, 1999; Battersby et al., 2006). Again, the format of the instruction and the test were identical to that of the pre-test conditions experienced by the test and control groups.

Variables

The responses from the computerized testing application were used as variables for the analysis. The dependent variables collected for analyses included *Percent Correct* (*PC*) and *Response Time* (*RT*). Each test question was recorded as correct or incorrect, allowing for later calculations of *Percent Correct*. *Response Times* in milliseconds were also recorded for all test questions. Independent variables included *Sex* (*SEX*), *Function* (*FUN*), *Manipulation* (*MAN*), and the unique study group and epoch combination (*TEST*). The *Function* represented the specific map overlay function represented in each test question. *Manipulation* refers to the portion of each test question that held the missing variable to be found (Table 4).

Table 4. Study variables and their use.

	Variables	Code	Definition	Examples
Independent	Function	*FUN*	The specific map overlay function being performed.	Intersect, Union, Erase
	Manipulation	*MAN*	The location of the missing variable in each test question.	First input (A1), Second input (A2), Function (B), Output (C)
	Subject Group & Epoch	*TEST*	A unique combination of subject group being tested and test epoch.	Third epoch of test group (CTE3), First epoch adult group (AE1)
	Sex	*SEX*	The sex of the subject being tested.	Male, Female
Dependent	Percent Correct	*PC*	The percentage of correct answers of a test.	90
	Reaction Time	*RT*	The time taken in milliseconds to answer each test question.	4016

Hypotheses

This study considered multiple hypotheses. First, it was hypothesized that map overlay schema development could be obtained in young adolescents through repetitive instruction and testing. The part-task practice component of the 4C/ID model has shown to be an effective means of learning in many studies (Van Merrienboer et al., 1992; Van Merrienboer, 1997; Van Merrienboer et al., 2002; Van Merrienboer et al., 2003). The incorporation of GIS into lessons of geographic concepts has also shown to be effective (Bednarz & Ludwig, 1997; Lo et al., 2002; Patterson et al., 2003). InGIScience research indicates that learning has been recorded in studies of part-task practice and GIS-incorporated lessons. Therefore, it stands to reason that the combination of these two approaches should lead to schema development.

Specific aspects of the map overlay concept were also under scrutiny. It was hypothesized that young adolescents would exhibit no differences in performance due to specific types of map overlay function. Previous studies show mixed results with respect to specific map overlay functions (Albert & Golledge, 1999; Battersby et al., 2006). Battersby and others (2006) specifically tested young adolescents and showed no significant differences within age group for proper use of specific map overlay functions. Albert and Golledge's (1999) study of undergraduate students measured the spatial cognitive abilities performed during map overlay operations and showed significant differences in the use of the different functions.

It was also hypothesized that young adolescents would exhibit no differences in performance due to spatial manipulations of map overlay operations. Albert and

Golledge's (1999) study incorporated tests in which the specific elements of input, function, or output within a map overlay operation were missing. This manipulation served to help gain an understanding of the levels of input or output shape complexity that affected performance. No specific results of significance were reported for the effect of the change of location of particular missing elements. This study sought to deepen our understanding of how map overlay operations are handled when their order of operation was altered.

Albert and Golledge (1999) found no significant differences in the performance of males and females in their study of map overlay. Other recent studies researching specific map-reading and GIS-related geographic concepts have reported similar results (Lloyd & Bunch, 2005; Lloyd & Bunch, 2010). The debate of spatial ability differences determined by biological sex has permeated relevant literature for decades. For this reason each participant's sex was recorded and included in the analyses. It was hypothesized that there would be no performance differences between young adolescent males and females in the map overlay concept.

Finally, it was hypothesized that performance of the young adolescents within the test group would increase until reaching a level equivalent to experts. Battersby and others (2006) encountered accuracy levels of students utilizing map overlay well above 90 percent. High school students recorded 94.3 percent accuracy while undergraduates recorded a perfect 100 percent. Terlecki and Newcombe (2005) observed that students engaged in practice consistently scored higher on each subsequent test without reaching a point of leveling off. It is expected that the test group's middle school students would continue to increase performance until reaching a point commensurate with the expert group’s undergraduate students.

CHAPTER IV

ANALYSIS AND RESULTS

Subject response data for all groups and epochs were collected and organized using a relational database and subject ID as the unique key. The dependent variables Percent Correct (*PC)* and Reaction Time (*RT)* were derived from the aggregation of data values into a Summary of Means on the basis of unique subject ID, *FUN*, *MAN*, *TEST*, and *SEX*. This aggregation ensured the preservation of observations for each subject tested and maintained the ability to identify responses to each unique combination of map overlay function and spatial cognitive manipulation. Prior to this aggregation, the ratio level data values (*RT*) were plotted on a histogram. The results indicated a positive skewness towards faster response times (Figure 25). These values were transformed using the natural log (ln) in order to achieve a normal distribution. After data values were aggregated, *PC* was calculated, and *RT* values were restored by calculating the inverse (exponent) of ln*RT*.

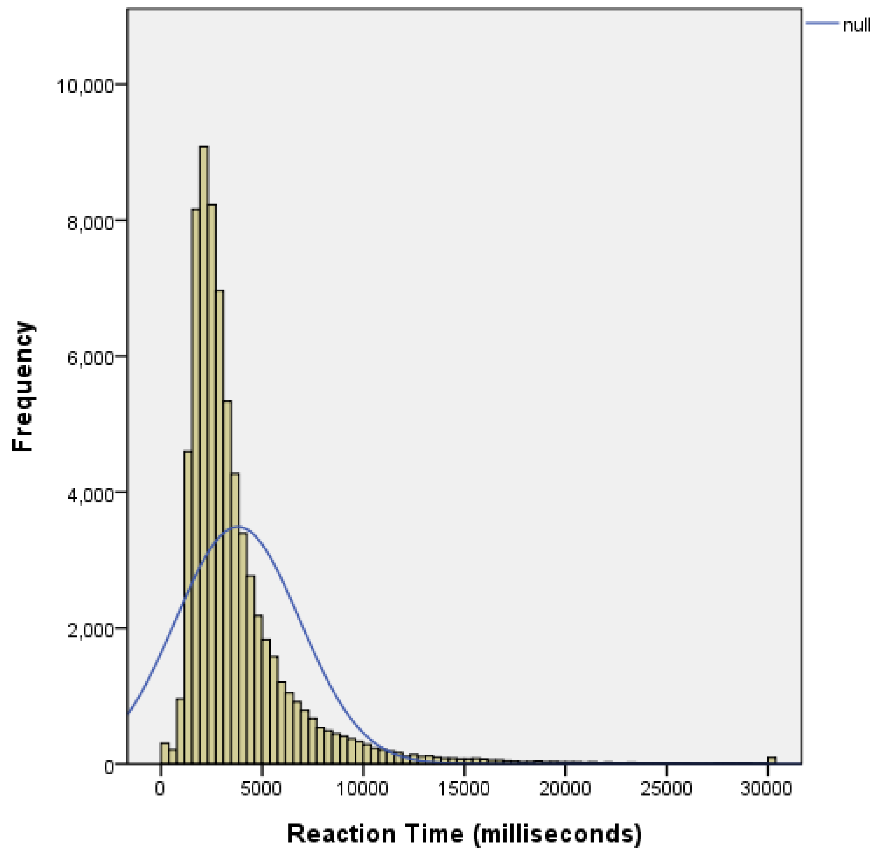


Figure 25. Histogram depicting skewed raw *RT* values.

Post-aggregation inspection of *RT* values revealed values well below or beyond normal expectations. Values near zero milliseconds indicated responses that were recorded in less time than it would take to read the question. Such responses were likely due to subjects inadvertently double-clicking the mouse and unknowingly answering the next question. Another possibility is that subjects became frustrated or bored with the test and simply clicked answers in order to finish the test faster. Other *RT* values were much greater than the average of 3791ms. It was observed that some subjects became either disinterested or fatigued while taking the test and simply stopped answering questions for a period of time. Values of these extremes are not a true representation of the abilities of the subjects and were regarded as outliers. The designation and treatment of *RT* outliers was handled using Tukey's Hinge method. Quartiles were established for the ranges of data within Datasets E1, E6, C16, and the epochs within Dataset CT. Upper and Lower Outer Fences were established by utilizing the corresponding formulas,

$$Upper\ Outer\ Fence = q75 + 3(hspread)$$

$$Lower\ Outer\ Fence = q25 - 3(hspread)$$

where *q75* and *q25* represent the 75 percent and 25 percent quartiles respectively, and *hspread* represents the difference between *q75* and *q25* (Tukey, 1977). Data values observed beyond Tukey's Upper and Lower Outer Fences were eliminated from the datasets (Table 5).

Table 5. Tukey's Hinges.

dataset	epoch	lower outer fence	upper outer fence
E1	1	-6342	14553
E6	6	-4956	11585
C16	1,6	-5613	12671
CT	1	-2451	11967
	2	-1997	10147
	3	-1567	8957
	4	-1355	8323
	5	-998	6952
	6	-837	6606

Subject response data were organized into four datasets for analysis. The first dataset called E1 included responses collected from subjects who took the adult epoch 1 (AE1), child control epoch 1 (CCE1), and child test epoch 1 (CTE1) conditions. This dataset represented the baseline knowledge of the map overlay concept for each study group. The second dataset called E6 included responses collected from subjects who took the adult epoch 1 (AE1), child control epoch 6 (CCE6), and child test epoch 6 (CTE6) conditions. This dataset represented the level of knowledge exhibited by each group at the conclusion of the study. By definition, the undergraduates (adults) were considered experts and did not require a sixth epoch test. Data from AE1 were used in lieu of a sixth epoch test. The third dataset called C16 included responses collected from subjects within four different conditions. The four groups consisted of the first and last epoch for the young adolescents in the child control group (CCE1, CCE6) and the first and last epoch for the young adolescent in the child test group (CTE1, CTE6). Each of these datasets was analyzed using a Multivariate Analysis of Variance (MANOVA) statistical model. *PC* and *RT* were treated as dependent variables whereas *SEX*, *FUN*, *MAN*, and *TEST* provided the main effects (Table 6). In each case, a Student-Newman-Keuls (S-N-K) range of means test was conducted to examine differences in means among categories.

Table 6. Statistical model used for all analyses.

Main Effects	**Category**
FUN	Intersect, Union, Erase
MAN	A1, A2, B, C
TEST	AE1, CCE1, CCE6, CTE1, CTE2, CTE3, CTE4, CTE5, CTE6
SEX	Male, Female
Dependent Variables	**Measurement**
PC	Percentage Correct
RT	Milliseconds

The fourth dataset CT consisted of responses from child test group subjects during epochs 1 through 6 (CTE1 through CTE6) conditions. This dataset represented temporal changes in *RT* and *PC* for the young adolescent test group who received repeated weekly instruction. The Dataset CT was analyzed using a Repeated Measures Analysis of Variance to examine moment to moment changes. Each dependent variable (*PC* and *RT)* was examined separately using *FUN*, *MAN*, *TEST*, and *SEX* as main effects (Table 6).

Dataset E1

The results of the MANOVA indicated that the model was statistically significant at $\alpha = 0.05$ (F=73761.730, P>F=0.000). Main effects *TEST*, *FUN*, and *MAN* were significant. Several interactions were also significant. These interactions included, *TEST**FUN*, *TEST**MAN*, *TEST**SEX*, *FUN**MAN*, *FUN**SEX*, and *TEST**FUN**SEX* (Table 7).

Table 7. Summary of MANOVA analysis based on Pillai's Trace (Dataset E1).

Main Effect	**F-Score**	**Probability > F**	**Observed Power**
TEST	84.0	0.000	1.00
FUN	243.9	0.000	1.00
MAN	14.4	0.000	1.00
Interaction Effect			
TEST and *FUN*	9.3	0.000	1.00
TEST and *MAN*	1.9	0.033	0.91
TEST and *SEX*	28.9	0.000	1.00
FUN and *MAN*	8.2	0.000	1.00
FUN and *SEX*	3.9	0.003	0.91
TEST and *FUN* and *SEX*	2.3	0.020	0.88

The univariate test of between-subjects effects for the dependent variable *PC* showed significance for the overall model at α = 0.05 (F=8.830, P>F=0.000). Main effects *TEST*, *FUN*, and *MAN* were found to be significant. The interactions *TEST**FUN*, *TEST**MAN*, *TEST**SEX*, *FUN**MAN*, and *FUN**SEX* were also significant (Table 8).

Table 8. Summary of univariate (*PC*) analysis based on Type III Sum of Squares (Dataset E1).

Main Effect	**F-Score**	**Probability > F**	**Observed Power**
TEST	10.1	0.000	0.99
FUN	220.5	0.000	1.00
MAN	3.6	0.013	0.79
Interaction Effect			
TEST and *FUN*	5.0	0.000	0.97
TEST and *MAN*	3.3	0.003	0.93
TEST and *SEX*	4.8	0.008	0.80
FUN and *MAN*	6.4	0.000	1.00
FUN and *SEX*	4.1	0.017	0.72

The univariate test of between-subjects effects for the dependent variable *RT* showed significance for the overall model at α = 0.05 (F=23.725, P>F=0.000). Significance was found for main effects *TEST*, *FUN*, and *MAN*. The interactions *TEST**FUN*, *TEST**SEX*, *FUN**MAN*, *FUN**SEX*, and *TEST**FUN**SEX* were also significant (Table 9).

Table 9. Summary of univariate (*RT*) analysis based on Type III Sum of Squares (Dataset E1).

Main Effect	F-Score	Probability > F	Observed Power
TEST	176.4	0.000	1.00
FUN	454.9	0.000	1.00
MAN	23.7	0.000	1.00
Interaction Effect			
TEST and *FUN*	14.4	0.000	1.00
TEST and *SEX*	54.9	0.000	1.00
FUN and *MAN*	10.4	0.000	1.00
FUN and *SEX*	4.7	0.010	0.79
TEST and *FUN* and *SEX*	3.3	0.010	0.85

Analysis of Category Means

Table 10 and Table 11 display the level of significance for each *TEST* category mean. Significant differences in *PC* were found between the means for the categories of CCE1 and both CTE1 and AE1 (Table 10). The *PC* mean for the child control group epoch 1 (90.90) is located within subset 1. *PC* means for child test group epoch 1 (92.63) and adult group epoch 1 (92.76) are located in subset 2. The location of mean values in difference subsets indicates statistical significance. The CCE1 mean was significantly different from the means of both CTE1 and AE1, while CTE1 and AE1 means are not significantly different from one another (Figure 26). Significant differences in *RT* were found between CCE1, CTE1, and AE1 (Table 11). The child test group epoch 1 (3558.14) recorded the fastest times, followed by the adult group epoch 1 (3926.85), and then the child control group epoch 1 (4609.04) with the slowest times (Figure 27).

Table 10. Means comparison of *PC* by *TEST* based on S-N-K (Dataset E1).

TEST	**N**	δ_M	***PC*** **Subset 1**	***PC*** **Subset 2**
CCE1	768	0.59	90.90	
CTE1	756	0.56		92.63
AE1	912	0.49		92.76
Sig.			1	0.851

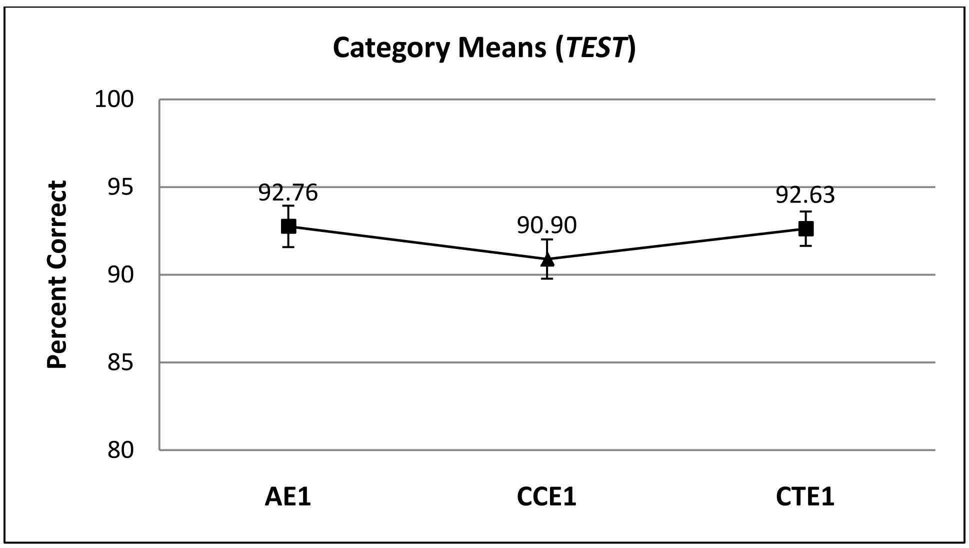


Figure 26. *PC* by *TEST* (Dataset E1). Dissimilar point symbols designate significantly different category means.

Table 11. Means comparison of *RT* by *TEST* based on S-N-K (Dataset E1).

TEST	**N**	δ_M	***RT*** **Subset 1**	***RT*** **Subset 2**	***RT*** **Subset 3**
CCE1	768	53.14	4609.04		
CTE1	756	45.79			3558.14
AE1	912	46.50		3926.85	
Sig.			1	1	1

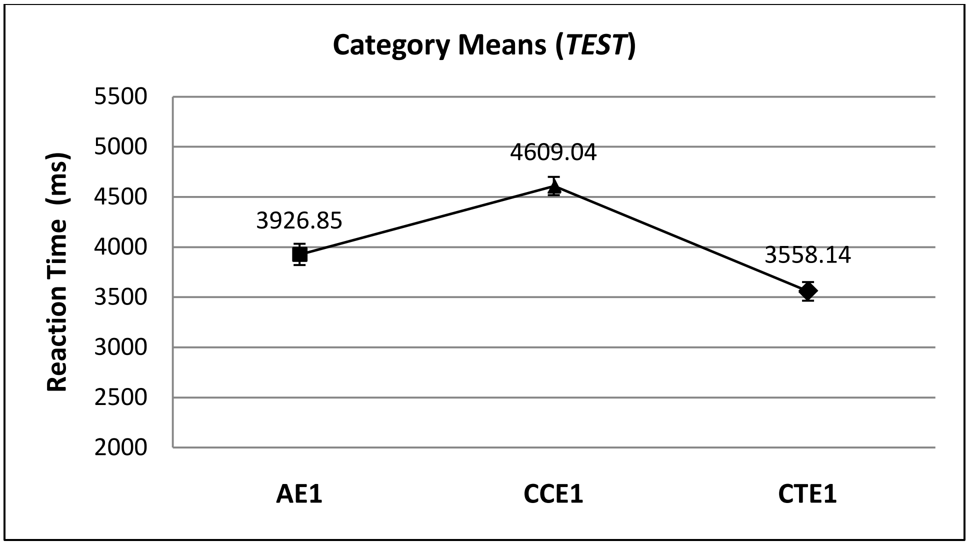


Figure 27. *RT* by *TEST* (Dataset E1). Dissimilar point symbols designate significantly different category means.

Category means for *FUN* were also analyzed by *PC* (Table 12) and *RT* (Table 13). Significant differences in *PC* were found for the INTERSECT (83.34) category, which had the lowest percent of correct answers when compared to both ERASE (95.70) and UNION (96.60) (Figure 28). Notably, the INTERSECT category also had the highest mean reaction times (5025.86), which was significantly different from all other categories. Mean reaction times for ERASE (3594.25), and UNION (3462.38) were also significantly difference from each other (Figure 29).

Table 12. Means comparison of *PC* by *FUN* based on S-N-K (Dataset E1).

FUN	N	δ_M	*PC* Subset 1	*PC* Subset 2
INTERSECT	812	0.70	83.34	
ERASE	812	0.37		95.70
UNION	812	0.35		96.60
Sig.			1	0.195

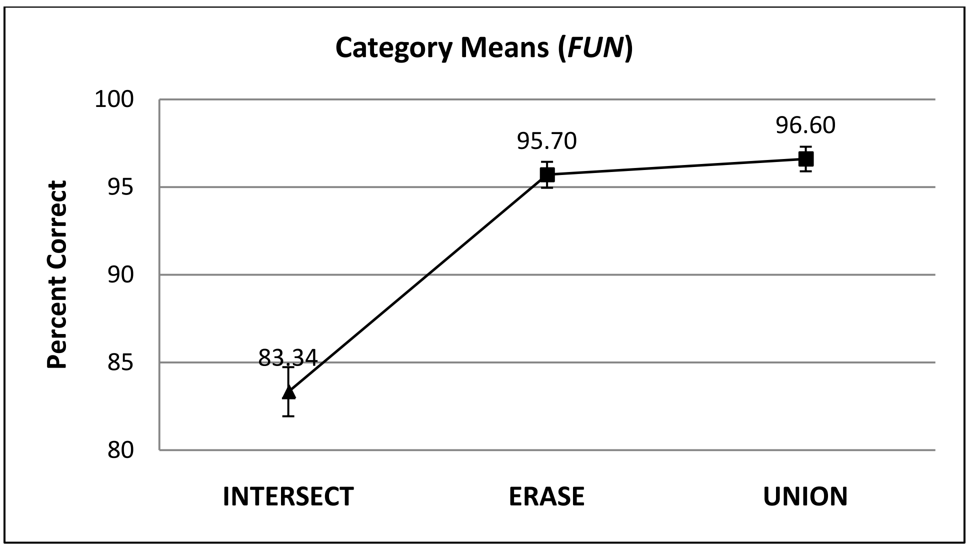


Figure 28. *PC* by *FUN* (Dataset E1). Dissimilar point symbols designate significantly different category means.

Table 13. Means comparison of *RT* by *FUN* based on S-N-K (Dataset E1).

FUN	N	δ_M	*RT* Subset 1	*RT* Subset 2	*RT* Subset 3
INTERSECT	812	56.50	5025.86		
ERASE	812	35.42		3594.25	
UNION	812	37.82			3462.38
Sig.			1	1	1

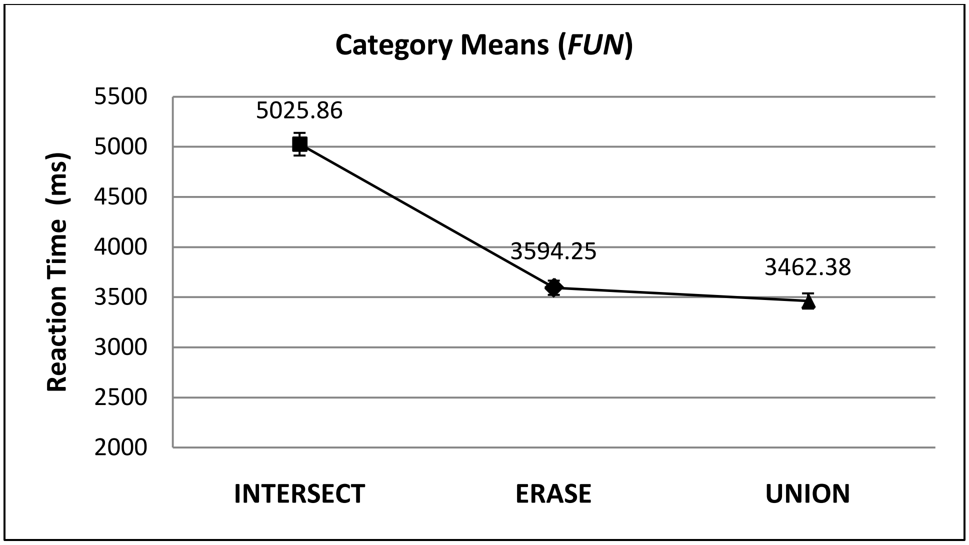


Figure 29. *RT* by *FUN* (Dataset E1). Dissimilar point symbols designate significantly different category means.

The results of the range of means test for *PC* and the categories associated with the variable *MAN* are displayed in Table 14. Significant differences in *PC* were found between the spatial manipulations C and both A1 and A2 (Table 14). The lowest percent correct was recorded when solving for the output (90.43) manipulation while the first input (92.79) and second input (92.78) manipulations elicited higher accuracy. The function (91.53), or map overlay operator, manipulation was not significantly different than any other manipulation (Figure 30). Significant differences of *RT* were found between B and A1, B and A2, C and A1, as well as C and A2 (Table 15). Subjects answered the function (3782.92) and output (3899.16) manipulations significantly faster than the first input (4185.33) and second input (4242.58) manipulations (Figure 31).

Table 14. Means comparison of *PC* by *MAN* based on S-N-K (Dataset E1).

MAN	**N**	δ_M	***PC*** Subset 1	***PC*** Subset 2
B	609	0.73	91.53	91.53
C	609	0.70	90.43	
A1	609	0.49		92.79
A2	609	0.55		92.78
Sig.			0.169	0.254

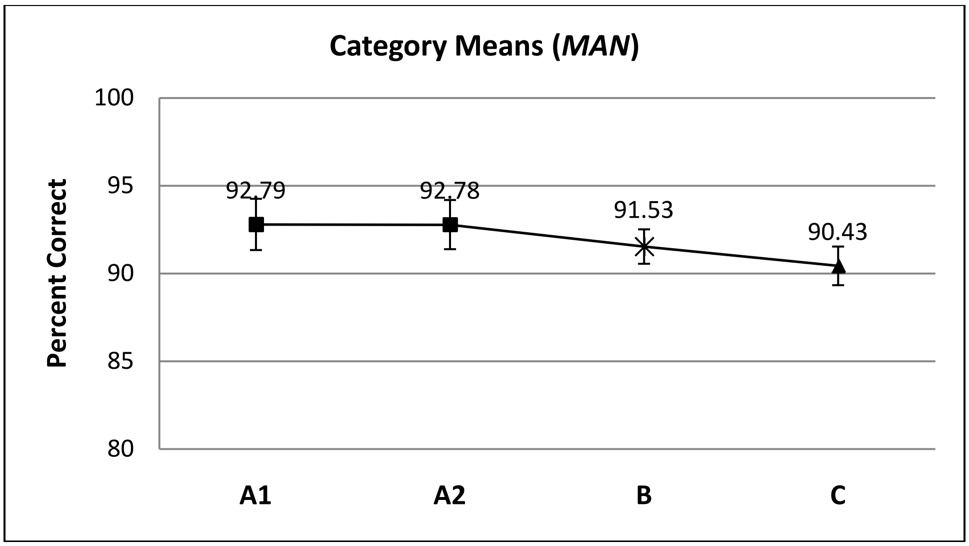


Figure 30. *PC* by *MAN* (Dataset E1). Dissimilar point symbols designate significantly different category means.

Table 15. Means comparison of *RT* by *MAN* based on S-N-K (Dataset E1).

MAN	**N**	δ_M	***RT*** Subset 1	***RT*** Subset 2
B	609	54.00	3782.92	
C	609	53.99	3899.16	
A1	609	61.49		4185.33
A2	609	62.42		4242.58
Sig.			0.071	0.373

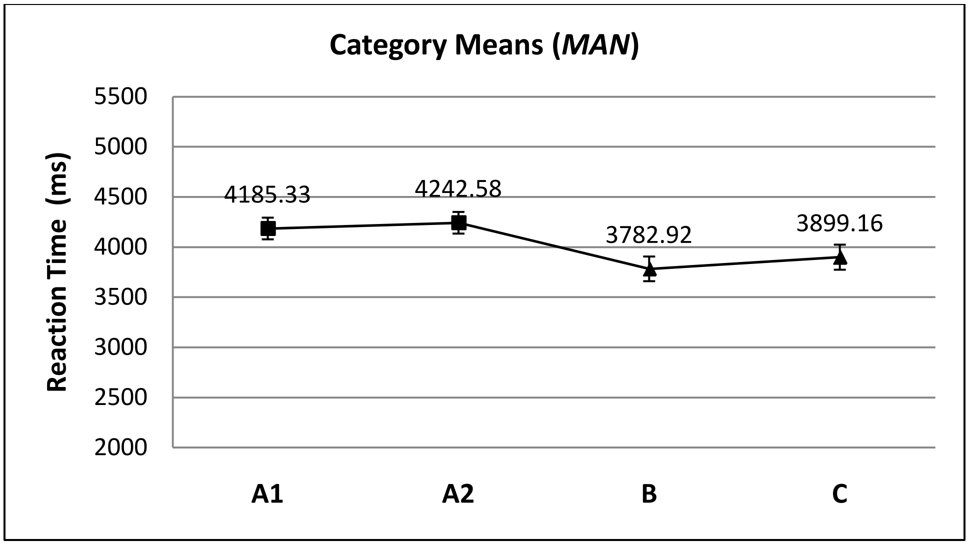


Figure 31. *RT* by *MAN* (Dataset E1). Dissimilar point symbols designate significantly different category means.

Discussion of Category Means

Dataset E1 is comprised of the initial (epoch 1) test data for each of the three groups; child control (CCE1), child test (CTE1), and adult (AE1). Univariate analysis found there was a significant difference in *PC* means of *TEST* between CTE1 and CCE1, but not between CTE1 and AE1. CTE1 and AE1 both had a higher mean *PC* than CCE1. There was a significant difference in *RT* means between all three groups. CCE1 had the longest times followed by AE1 and CTE1 respectively. These observations are contrary to what was expected and differ with respect to the child test group from results of previous map overlay studies (Battersby et al., 2006). Battersby and others (2006) found that undergraduate students significantly recorded more correct answers than middle school students. Results of the current study support previous work with respect to performance of the child control group, while raising additional questions concerning the high performance of the child test group. The observations of differences between the child groups and the lack of difference between the test and adult group for *PC* were unexpected and cannot be easily explained. It should be noted that the child test group was tested earlier in the mornings than the child control group. It could be possible that the child test group was more focused during the early morning hours of a school day, and the child control group was anticipating the approaching mid-day/lunch break during the later morning hours. This type of environment could have resulted in the high performances of CTE1 answering quicker and more correctly during the test. Having chosen the members of both groups at random, this is the only outward apparent difference between the two groups.

In addition to observations made between *TEST* (group) categories, differences within *FUN* (function) and *MAN* (manipulation) were also recorded. *PC* means were significantly higher for the functions of UNION and ERASE than the INTERSECT function. Means of *RT* were significant between all three functions. UNION had the lowest times followed next by ERASE and then INTERSECT. With respect to the intersect function, these results counter those of Battersby and others (2006) in which no differences between map overlay function categories were observed for any group. Conceptually the results of the current study make sense. The union function can be compared to the arithmetical process of addition. Two objects are joined or added to form the combination or sum object. Comparatively, the erase and intersect functions are two-step processes. Arithmetically they are more similar to the subtraction process. Two objects are combined and the overlapping area is erased or subtracted from the resulting object. It makes sense that this two-step process would take more time to calculate. The difference in complexity between these two functions is based on the appearance of the resulting object inherent to each function. The resultant erase object has many of the same characteristic features of the parent, pre-erase objects. The overall outer edge of the resultant object most often retains the distinct angles and patterns of the parent objects, only now having a new empty space where any overlap occurred. The resultant intersect object is comprised merely of the area common to the parent objects. Most often, this dictates that the familiar outer edges of the parent objects will not be present in the resultant object, thus making it more difficult to recognize quickly and correctly.

With regard to *MAN*, significant differences in the means of *PC* and *RT* were found between the C (output) manipulation and both the A1 and A2 (input) manipulations. *PC* means revealed that C was more difficult to answer correctly than any other missing value. The highest *PC* means were recorded for A1 and A2 manipulations. Along with the C, the B (function) manipulation also recorded significantly lower *RT* means from both A1 and A2. Missing inputs required more time to answer than the missing function or output. The observed differences in time were to be expected since the absence of an input requires the student to work the operation in a reverse manner. The pattern of high *PC* means paired with high *RT* means, and a corresponding pairing of low values of each variable illustrates a sometimes common theme during testing scenarios. The additional time taken to determine the missing inputs could help to explain the higher *PC* for these questions.

Analysis of Interaction Effects

Statistical significance was found for the two-way interaction *TEST* and *FUN* for both dependent variables *PC* (Table 8) and *RT* (Table 9). The adult, child control, and child test groups each had distinctively lower *PC* (Table 16, Figure 32) and higher *RT* (Table 17, Figure 33) values for the INTERSECT function than the ERASE and UNION functions. For each group, INTERSECT equated to *PC* values 10 to 15 percent lower and *RT* values 1 to 1.5 seconds longer than the other functions.

Table 16. Means comparison of *PC* by *TEST* and *FUN* (Dataset E1).

TEST	**N**	δ_M	***PC* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
AE1	912	0.82	85.86	95.76	97.42
CCE1	768	0.87	79.10	95.40	95.84
CTE1	756	0.88	85.38	96.14	96.42

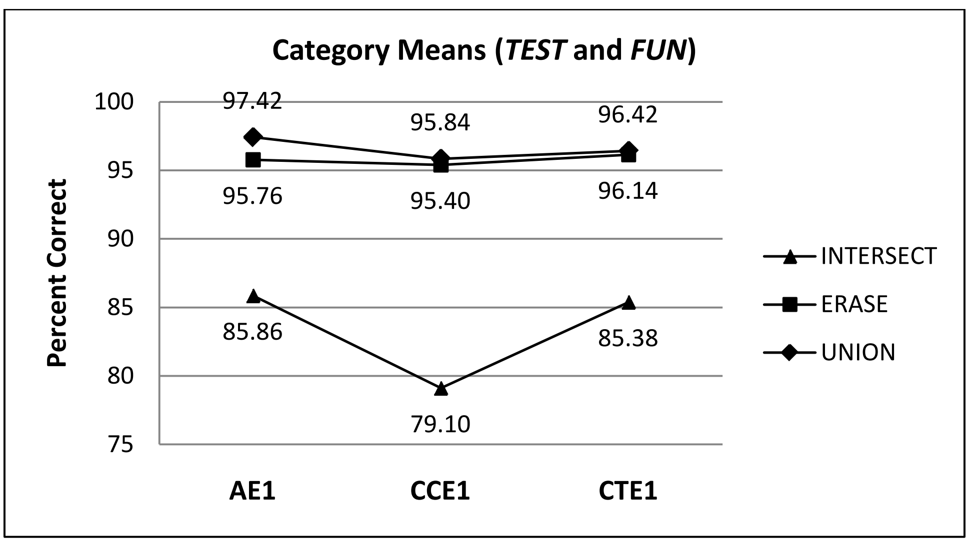


Figure 32. The two-way interaction effect on *PC* for *TEST* and *FUN* (Dataset E1).

Table 17. Means comparison of *RT* by *TEST* and *FUN* (Dataset E1).

TEST	**N**	δ_M	***RT* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
AE1	912	65.79	4958.81	3447.59	3171.17
CCE1	768	70.12	5782.04	3960.21	4074.58
CTE1	756	70.65	4216.44	3341.80	3127.01

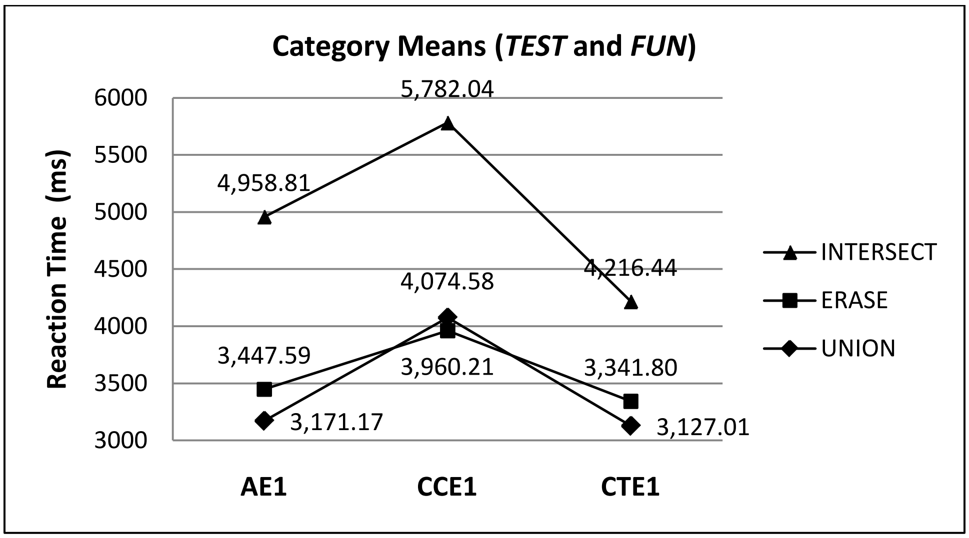


Figure 33. The two-way interaction effect on *RT* for *TEST* and *FUN* (Dataset E1).

TEST and *MAN* also revealed statistical significance between categories with respect to *PC* (Table 8). The adult, child control, and child test groups each had similar first and second input manipulation values (Table 18). Notable decreases in *PC* were observed with the output manipulation for both the adult and child control groups as well as with the function manipulation for the child control group (Figure 34).

Table 18. Means comparison of *PC* by *TEST* and *MAN* (Dataset E1).

TEST	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
AE1	912	0.95	93.90	94.28	93.83	89.95
CCE1	768	1.01	91.58	92.03	87.10	89.76
CTE1	756	1.02	92.84	92.02	93.79	91.93

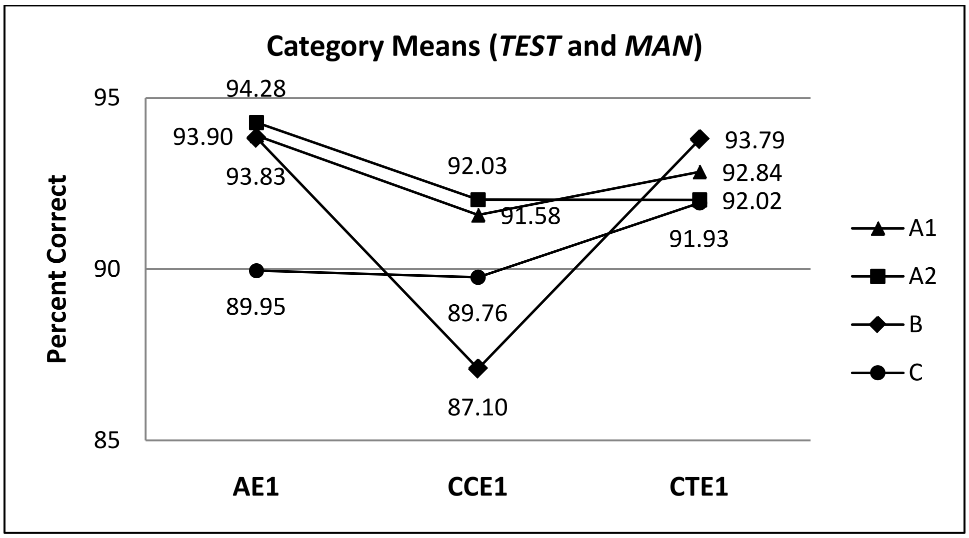


Figure 34. The two-way interaction effect on *PC* for *TEST* and *MAN* (Dataset E1).

The two-way interaction between *TEST* and *SEX* exhibited statistical significance with respect to *PC* (Table 8) and *RT* (Table 9). Females in the adult, child control, and child test groups showed consistent *PC* values across all groups (Table 19). Males within the adult and child test groups scored distinctively higher than their in-group females, while males of the child control group scored lower than their female counterparts (Figure 35). With respect to *RT*, males and females generally followed the same pattern across groups with the child control group recording higher values than subjects from any other group (Table 20, Figure 36).

Table 19. Means comparison of *PC* by *TEST* and *SEX* (Dataset E1).

TEST	**N**	***PC* by *SEX***			
		Male	δ_M	**Female**	δ_M
AE1	912	94.19	0.74	91.83	0.59
CCE1	768	89.29	0.70	90.94	0.72
CTE1	756	93.55	0.72	91.75	0.71

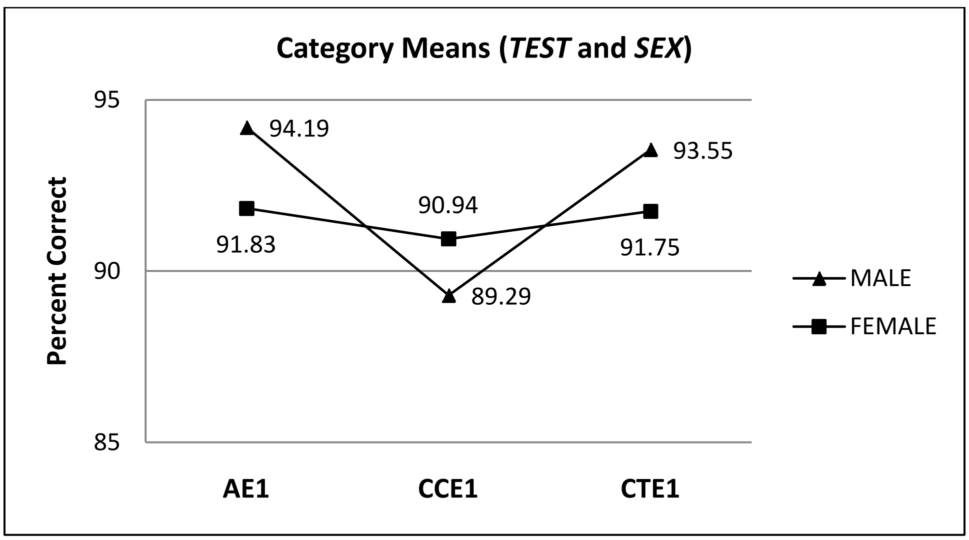


Figure 35. The two-way interaction effect on *PC* for *TEST* and *SEX* (Dataset E1).

Table 20. Means comparison of *RT* by *TEST* and *SEX* (Dataset E1).

TEST	**N**	***RT* by *SEX***			
		Male	δ_M	**Female**	δ_M
AE1	912	3537.79	59.11	4180.59	47.73
CCE1	768	4715.21	56.35	4496.02	58.14
CTE1	756	3789.35	58.14	3334.15	57.23

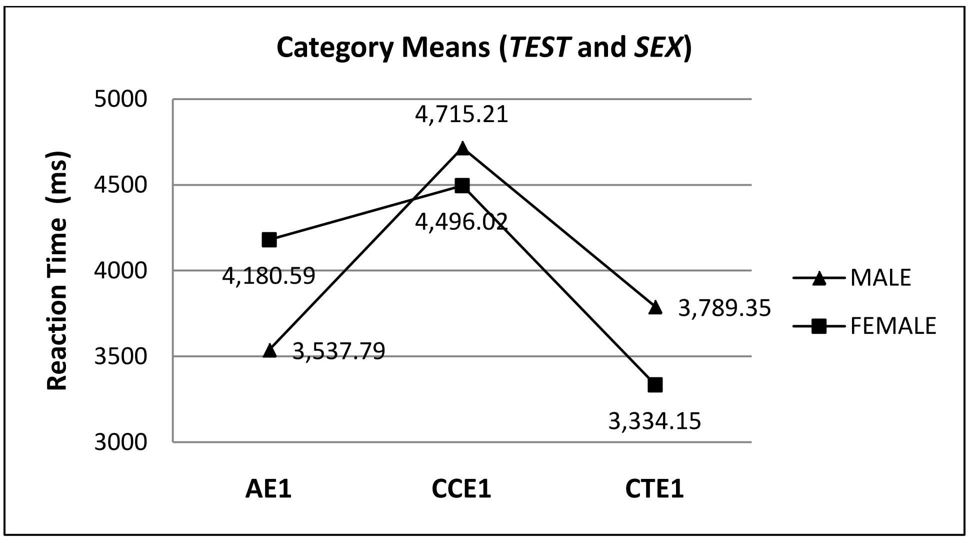


Figure 36. The two-way interaction effect on *RT* for *TEST* and *SEX* (Dataset E1).

PC (Table 8) and *RT* (Table 9) contained statistical significance for the two-way interaction between *FUN* and *MAN*. In general, the input manipulations were responsible for relatively low *PC* (Table 21) values and high *RT* (Table 22) values with respect to the INTERSECT function. Another interesting pattern was found with questions pertaining to the B manipulation. *PC* values were lower for this manipulation than those recorded for ERASE and UNION functions, but were higher for the INTERSECT function (Figure

37). *RT* values were found to be nearly a second lower for the B manipulation when considering the INTERSECT function (Figure 38).

Table 21. Means comparison of *PC* by *FUN* and *MAN* (Dataset E1).

FUN	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	812	0.99	82.92	82.51	87.05	81.31
ERASE	812	0.99	97.93	98.11	93.65	93.38
UNION	812	0.99	97.56	97.70	94.02	96.95

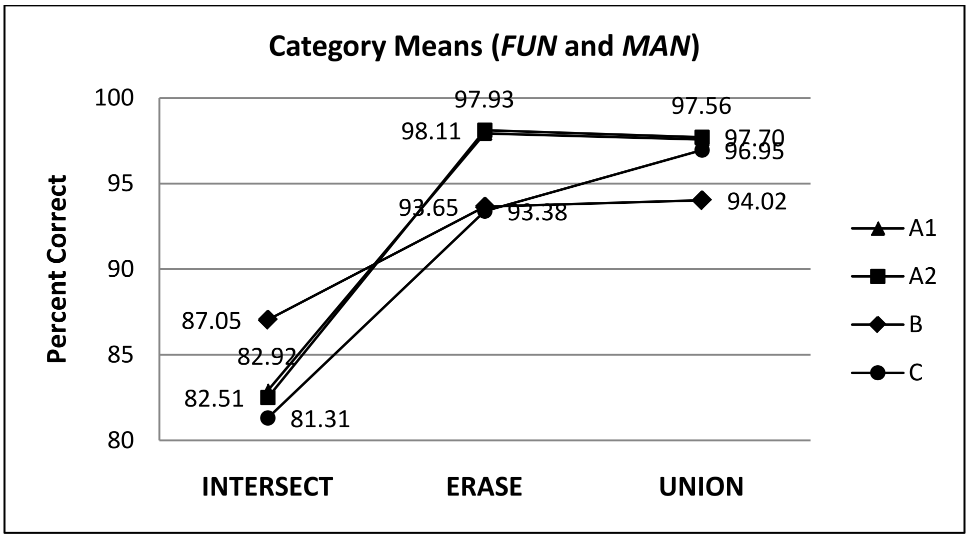


Figure 37. The two-way interaction effect on *PC* for *FUN* and *MAN* (Dataset E1).

Table 22. Means comparison of *RT* by *FUN* and *MAN* (Dataset E1).

FUN	**N**	δ_M	***RT* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	812	79.55	5318.97	5471.92	4593.57	4558.61
ERASE	812	79.55	3734.25	3779.00	3295.87	3523.68
UNION	812	79.55	3454.42	3423.16	3398.15	3554.62

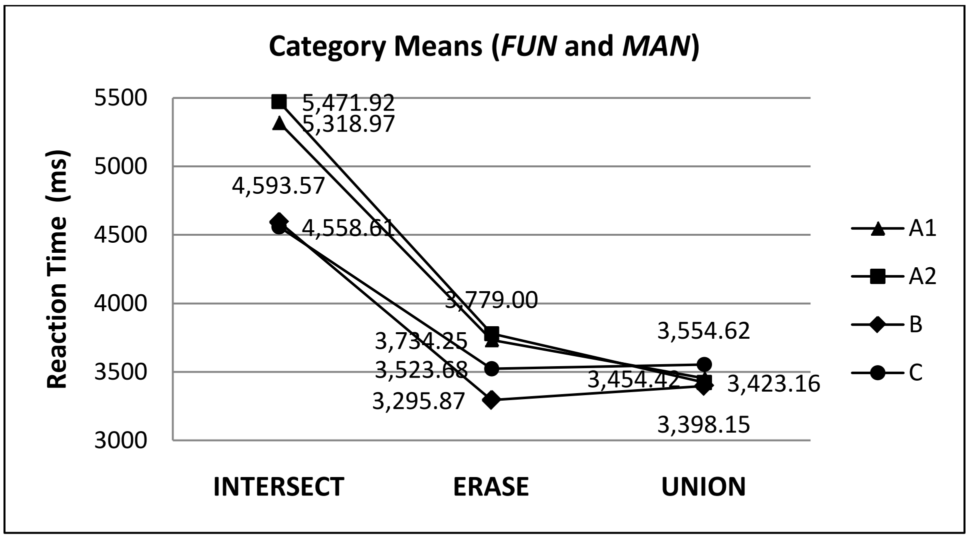


Figure 38. The two-way interaction effect on *RT* for *FUN* and *MAN* (Dataset E1).

It was revealed that statistical significance existed for the two-way interaction between *FUN* and *SEX* with respect to *PC* (Table 8) and *RT* (Table 9). Males recorded higher values of *PC* on questions pertaining to INTERSECT and UNION functions, while females outscored males on the ERASE function (Table 23, Figure 39). Females recorded lower *RT* values on ERASE and UNION functions, while males answered faster on questions of the INTERSECT function (Table 24, Figure 40).

Table 23. Means comparison of *PC* by *FUN* and *SEX* (Dataset E1).

FUN	**N**	***PC* by *SEX***			
		Male	δ_M	**Female**	δ_M
INTERSECT	812	84.90	0.72	81.99	0.68
ERASE	812	95.23	0.72	96.31	0.68
UNION	812	96.91	0.72	96.22	0.68

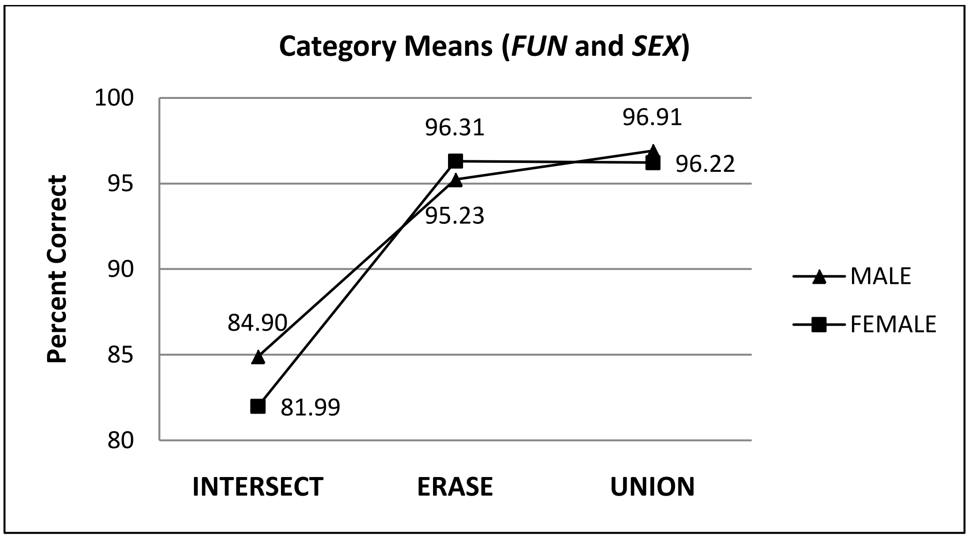


Figure 39. The two-way interaction effect on *PC* for *FUN* and *SEX* (Dataset E1).

Table 24. Means comparison of *RT* by *FUN* and *SEX* (Dataset E1).

FUN	**N**	***RT* by *SEX***			
		Male	δ_M	**Female**	δ_M
INTERSECT	812	4893.85	57.88	5077.68	54.57
ERASE	812	3653.76	57.88	3512.64	54.57
UNION	812	3494.74	57.88	3420.44	54.57

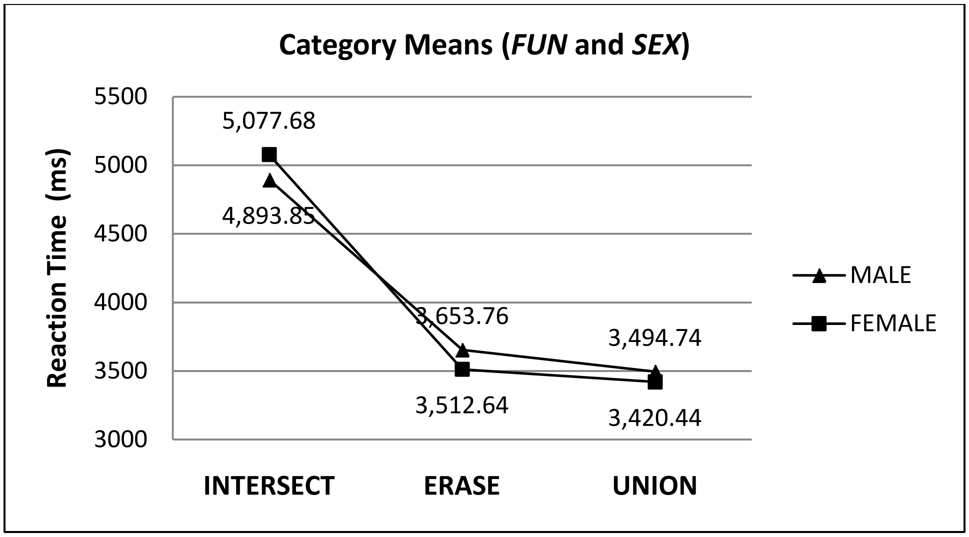


Figure 40. The two-way interaction effect on *RT* for *FUN* and *SEX* (Dataset E1).

A three-way interaction was also found to be significant in *RT* for *TEST* and *FUN* and *SEX*. Of interest to this study, the most notable and interesting observations among all combination groups was the performance of the child test group females compared to the child test group males across all functions. *RT* values demonstrated by females for INTERSECT (3921.74), ERASE (3097.30), and UNION (2983.41) were all distinctly lower than the respective values of their male counterparts; (4511.15), (3586.29), and (3270.61).

Discussion of Interaction Effects

Analysis of the interaction between *TEST* and *FUN* indicated that significance was observed between the child control group and both the adult and child test groups with regard to the type of map overlay function tested. Each function, especially INTERSECT, was significantly more difficult to perform and took longer to answer for the child control group than the other groups. With respect to *PC*, this was expected in accordance with the results of the univariate analysis. However, the child control group recorded the longest *RT* values for the INTERSECT function, and this was not expected. Univariate analysis confirmed that the child control group recorded significantly lower *RT* values than the other groups. The child control group followed the pattern of performance observed in a previous study conducted by Battersby and others (2006). The previous study found that middle schoolers recorded a significantly lower number of correct answers than older students for each of the logical operators 'NOT', 'OR', and 'AND', corresponding to the functions ERASE, UNION, and INTERSECT respectively. The observation that middle schoolers had an exceptional amount of trouble with the INTERSECT function follows Albert and Golledge's (1999) findings that even undergraduate students (experts) demonstrate low performance with the 'AND' (INTERSECT) operator as opposed to the 'XOR' (ERASE) and 'OR' (UNION) operators.

Interaction between *TEST* and *MAN* followed earlier observations in that the child control group recorded a much lower *PC* mean in combination with the B (function) manipulations than any other combination analyzed. It was also observed that the adult and child control groups recorded much lower *PC* values for C (output) manipulations than the child test group; however the output manipulation proved most difficult for the child test group as well. Whereas the B manipulation exhibited the highest *PC* means under univariate analysis, it is noteworthy that the adult and child test group performed very well on this manipulation, underscoring the overall impact that the child control group contributed within the univariate analysis. These results indicate that perhaps the B manipulation was not the most difficult, but rather the C manipulation.

While *SEX* was not significant for the overall model, the interaction with *TEST* proved significant. Adult and child test group males recorded higher *PC* values than their groups' females, while child control group females scored higher than their group's males. Adult males answered questions faster than adult females, but more interesting were the child test group females, which answered questions much faster than all other subjects including the adult males.

The interaction between *FUN* and *MAN* can be generalized in stating that regardless of manipulation, all questions involving INTERSECT had high values of *RT* and low values of *PC*. Within this generality, the manipulations A1 and A2 represented values at the extreme. This was to be expected as previous studies (Albert & Golledge, 1999; Battersby et al., 2006) and the univariate analysis found similar results regarding the use of map overlay intersect. Also interesting is the fact that the B manipulation proved to be the easiest combination with INTERSECT, while also the hardest in combination with ERASE and UNION. This may be explained by the nature of the output shape within INTERSECT questions. The intersect map overlay function results in the preservation of areas only common to both input shapes. Naturally, this results in an output shape that is often much smaller than either of the input shapes. It would not take a great leap of faith to imagine subjects noticing a small output shape and very quickly selecting 'INTERSECT' as their B manipulation answer.

The interaction between *FUN* and *SEX* was also found to be significant. While plots of *PC* and *RT* means were similar, it can be noticed that with respect to the INTERSECT function, males tended to exhibit a higher *PC* and lower *RT* than females.

The three-way interaction between *TEST* and *FUN* and *SEX* for *RT* was interesting when analyzed against the adult group. The adult males recorded values lower than the adult females for all conditions of *FUN*. The observed *RT* values of the child test group are opposite of those observed by the expert group. These observations within Dataset E1 represent baseline knowledge of all subjects. No statistical significance was found for this interaction with respect to *PC*. Young adolescent females appear to have an advantage over young adolescent males with respect to required processing time within working memory for map overlay.

Dataset E6

The results of the MANOVA indicated that the model was statistically significant at $\alpha = 0.05$ (F=106753.591, P>F=0.000). Main effects *TEST*, *FUN*, and *MAN* were significant. Several interactions were also significant. These interactions included, *TEST***FUN*, *TEST***MAN*, *TEST***SEX*, *FUN***MAN*, *TEST***FUN***MAN*, and *TEST***FUN***SEX* (Table 25).

Table 25. Summary of MANOVA analysis based on Pillai's Trace (Dataset E6).

Main Effect	F-Score	Probability > F	Observed Power
TEST	225.8	0.000	1.00
FUN	149.0	0.000	1.00
MAN	16.6	0.000	1.00
Interaction Effect			
TEST and *FUN*	22.8	0.000	1.00
TEST and *MAN*	4.1	0.000	1.00
TEST and *SEX*	22.0	0.000	1.00
FUN and *MAN*	13.1	0.000	1.00
TEST and *FUN* and *MAN*	4.1	0.000	1.00
TEST and *FUN* and *SEX*	2.1	0.033	0.85

The univariate test of between-subjects effects for the dependent variable *PC* showed significance for the overall model at $\alpha = 0.05$ (F=12.119, P>F=0.000). Main effects *TEST*, *FUN*, and *MAN* were found to be significant. The interactions *TEST**FUN*, *TEST**MAN*, *TEST**SEX*, *FUN**MAN*, *TEST**FUN**MAN*, and *TEST**FUN**SEX* were also significant (Table 26).

Table 26. Summary of univariate (*PC*) analysis based on Type III Sum of Squares (Dataset E6).

Main Effect	F-Score	Probability > F	Observed Power
TEST	11.5	0.000	0.99
FUN	214.3	0.000	1.00
MAN	10.6	0.000	1.00
Interaction Effect			
TEST and *FUN*	8.5	0.000	1.00
TEST and *MAN*	7.1	0.000	1.00
TEST and *SEX*	8.7	0.000	0.97
FUN and *MAN*	21.9	0.000	1.00
TEST and *FUN* and *MAN*	6.8	0.000	1.00
TEST and *FUN* and *SEX*	2.7	0.027	0.76

The univariate test of between-subjects effects for the dependent variable *RT* showed significance for the overall model at $\alpha = 0.05$ (F=28.703, P>F=0.000). Significance was found for main effects *TEST*, *FUN*, *MAN*, and *SEX*. The interactions *TEST**FUN*, *TEST**SEX*, and *FUN**MAN* were also significant (Table 27).

Table 27. Summary of univariate (*RT*) analysis based on Type III Sum of Squares (Dataset E6).

Main Effect	F-Score	Probability > F	Observed Power
TEST	557.2	0.000	1.00
FUN	163.9	0.000	1.00
MAN	25.2	0.000	1.00
SEX	4.5	0.034	0.57
Interaction Effect			
TEST and *FUN*	38.7	0.000	1.00
TEST and *SEX*	53.4	0.000	1.00
FUN and *MAN*	6.5	0.000	1.00

Analysis of Category Means

A range of means test was performed to further examine category means for the variable *TEST*. The child test group epoch 6 (95.20) recorded a significantly higher *PC* mean than both the child control group epoch 6 (92.71) and the adult group epoch 1 (92.76) (Table 28, Figure 41). The child test group epoch 6 (2330.75) also recorded the significantly fastest *RT*, followed by the child control group epoch 6 (3674.96), and then the adult group epoch 1 (4609.04) (Table 29, Figure 42).

Table 28. Means comparison of *PC* by *TEST* based on S-N-K (Dataset E6).

TEST	**N**	δ_M	***PC***	
			Subset	
			1	**2**
CCE6	768	0.46	92.71	
CTE6	756	0.38		95.20
AE1	912	0.48	92.76	
Sig.			0.922	1

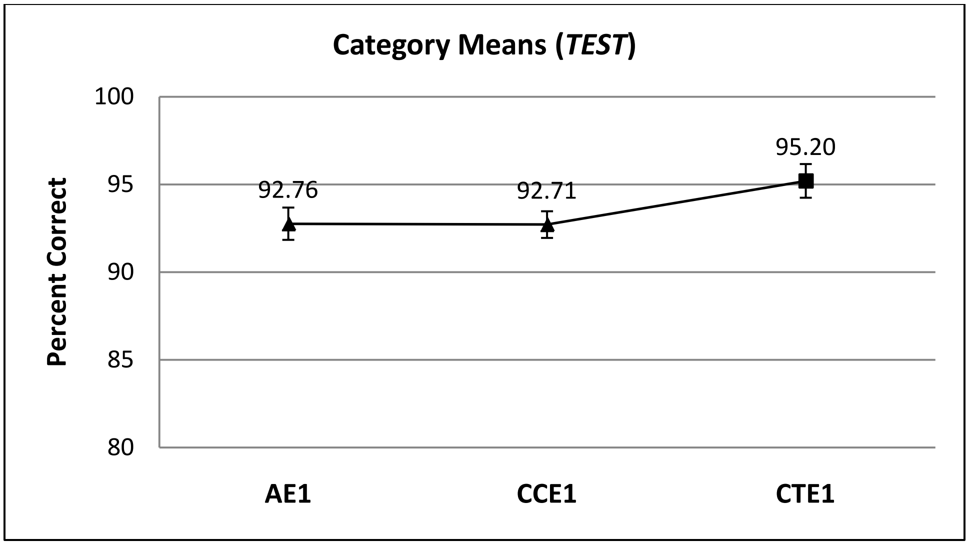


Figure 41. *PC* by *TEST* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Table 29. Means comparison of *RT* by *TEST* based on S-N-K (Dataset E6).

TEST	**N**	δ_M	***RT***		
			Subset		
			1	**2**	**3**
CCE6	768	43.52		3674.96	
CTE6	756	23.42	2330.75		
AE1	912	40.92			4609.04
Sig.			1	1	1

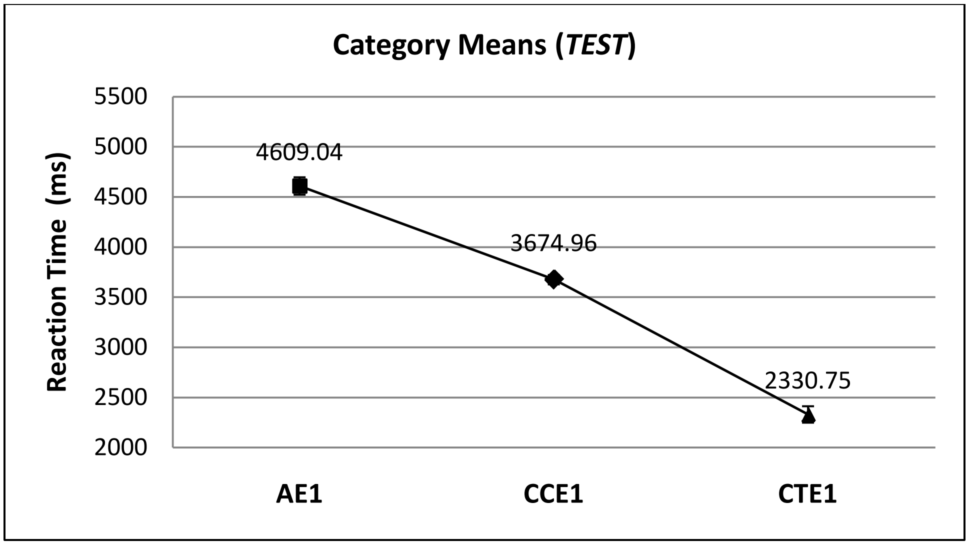


Figure 42. *RT* by *TEST* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Category means and their level of significance with respect to *PC* and the variable *FUN* are illustrated in Table 30. Significant differences in *PC* were found between the category means for INTERSECT (86.63) which yielded the lowest number of correct answers and both ERASE (96.49) and UNION (97.39) (Figure 43). Consistent with the results of *PC*, INTERSECT questions represented the lowest performance values of *RT* (Table 31). Significant differences in *RT* were found between each of the categories INTERSECT (3832.28), ERASE (3092.83), and UNION (2987.42) (Figure 44).

Table 30. Means comparison of *PC* by *FUN* based on S-N-K (Dataset E6).

FUN	**N**	δ_M	***PC*** **Subset 1**	***PC*** **Subset 2**
INTERSECT	812	0.60	86.63	
ERASE	812	0.33		96.49
UNION	812	0.24		97.39
Sig.			1	0.106

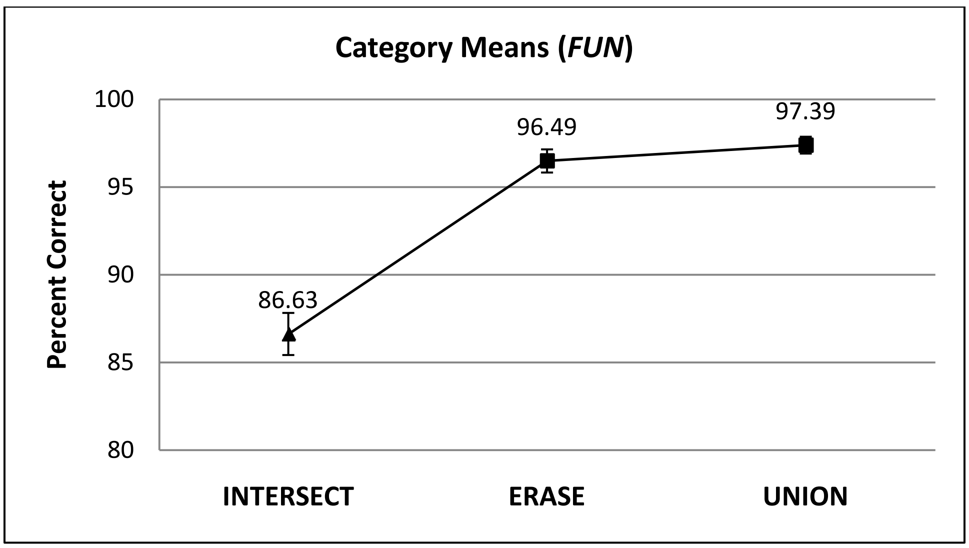


Figure 43. *PC* by *FUN* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Table 31. Means comparison of *RT* by *FUN* based on S-N-K (Dataset E6).

FUN	**N**	δ_M	***RT*** **Subset 1**	***RT*** **Subset 2**	***RT*** **Subset 3**
INTERSECT	812	51.24	3832.28		
ERASE	812	37.55		3092.83	
UNION	812	36.20			2987.42
Sig.			1	1	1

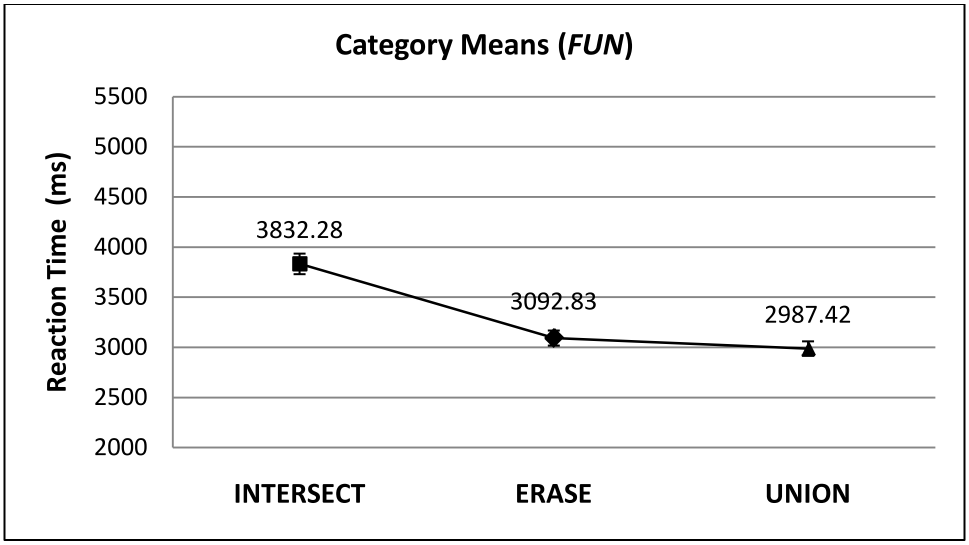


Figure 44. *RT* by *FUN* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Significant differences in the category means of *MAN* with respect to *PC* were also found (Table 32). The mean of spatial manipulation B was significantly different from each of the means of A1, A2, and C. The highest percent correct was recorded when solving for the function (95.55) manipulation while the first input (93.33), second input (92.50), and output (92.63) manipulations elicited lower accuracy (Figure 45). Significant differences in *RT* were found between each of the manipulations with the exception of A1 and A2, which were not significantly different than one another (Table 33). Subjects answered the function (3088.90) manipulation fastest, followed by the output (3201.85) manipulation, and then the first (3429.40) and second (3496.56) input manipulations (Figure 46).

Table 32. Means comparison of *PC* by *MAN* based on S-N-K (Dataset E6).

MAN	**N**	δ_M	***PC*** Subset 1	***PC*** Subset 2
B	609	0.46		95.55
C	609	0.58	92.63	
A1	609	0.50	93.33	
A2	609	0.53	92.50	
Sig.			0.392	1

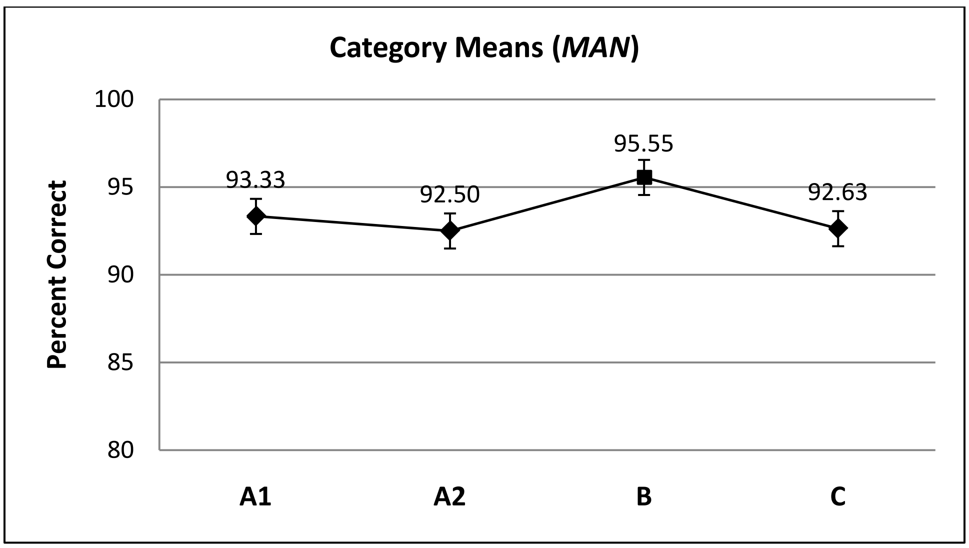


Figure 45. *PC* by *MAN* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Table 33. Means comparison of *RT* by *MAN* based on S-N-K (Dataset E6).

MAN	**N**	δ_M	***RT*** Subset 1	***RT*** Subset 2	***RT*** Subset 3
B	609	51.23	3088.90		
C	609	48.11		3201.85	
A1	609	51.17			3429.40
A2	609	51.95			3496.56
Sig.			1	1	0.211

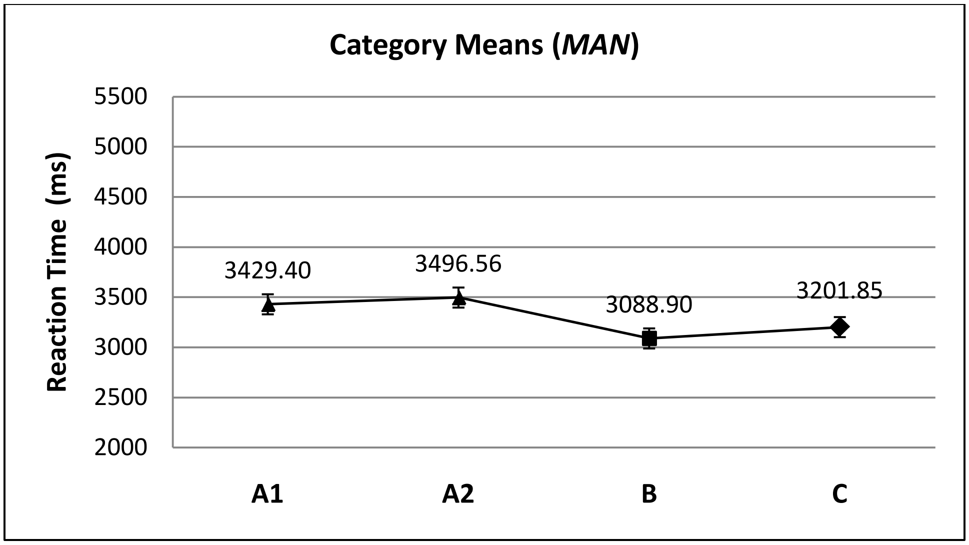


Figure 46. *RT* by *MAN* (Dataset E6). Dissimilar point symbols designate significantly different category means.

Discussion of Category Means

Dataset E6 is comprised of the final (epoch 6) test data for each of the three groups; child control (CCE1), child test (CTE1), and adult (AE1). The results for AE1 were used to represent the adult (expert) group since post-adolescent subjects are believed to possess mature map overlay concept processes (Battersby et al., 2006). Univariate analysis found significant differences in *PC* means of *TEST* between CTE6 and both CCE6 and AE1. CTE6 exhibited a higher *PC* than the other groups. There was a significant difference for *RT* between all three groups. CTE6 exhibited the lowest times followed next by CCE6 and then AE1. These results indicate that while the young adolescent groups both increased the *PC* of the E6 test over the E1 test, the child test group exceeded even that of the adult group. The child test group was also able to achieve this high *PC* while significantly lowering the *RT* below the other groups. The child test group achieved the highest *PC* and lowest *RT* of all three groups. Also of note is the performance of the child control group. The E6 test marked the second experience these subjects had with the material. This group recorded *PC* values in accordance with the adult group while outperforming those experts with respect to *RT* values. Cherney and Neff (2004) showed that test-taking experiences proved to be effective practice. While acknowledging that tests from different epochs contained wholly unique questions, perhaps the simple act of taking a second test proved to enhance the performance of the child control group subjects to levels even with or greater than those of the adult group.

Areas of significance for *FUN* were found to be the same as that of Dataset E1. UNION and ERASE were again higher than INTERSECT with regard to the means of *PC*, and UNION had the lowest *RT* means followed by ERASE and then INTERSECT. Overall, *PC* increased and *RT* decreased for each function indicating increased efficiency with the tasks, however relative performance remained the same between epoch 1 and epoch 6. The continuation of the INTERSECT function being the most difficult of the functions is supported by the findings of Albert and Golledge (1999) discussed earlier. The undergraduate students in the 1999 study demonstrate that this function is inherently difficult and is not necessarily improved upon through time.

There was a significant difference in *PC* and *RT* for *MAN* between the B (function) manipulation versus all other manipulations. Both A1 and A2 manipulations recorded values similar to those from the first epoch; however gains were experienced by both the C and B manipulations, with B significantly higher than others. Again, and for the same possible reasons experienced during the first epoch, the manipulations of B and

C recorded lower *RT* values than the A1 and A2 manipulations. The higher performance by subjects with respect to the B manipulation may infer that different cognitive processes took place while solving for the types of manipulations within this study. The manipulations of A1, A2, and C required the subject to mentally search for shapes that needed to be added or subtracted from each other in some way. The B manipulation only required the subject to recognize what operation had taken place. All shapes within the question were present, and the subject merely needed to recognize the function represented. Mental processing of shapes representing possible answers was necessary.

Analysis of Interaction Effects

Statistical significance was found for the two-way interaction between *TEST* and *FUN* with respect to *PC* (Table 26) and *RT* (Table 27). The adult, child control, and child test groups each had distinctively lower *PC* (Table 34) and higher *RT* (Table 35) values for the INTERSECT function than the EARSE and UNION functions. For each group, INTERSECT equated to *PC* values around 10 percent lower (Figure 47) and *RT* values up to 1.5 seconds longer (Figure 48) than the other functions.

Table 34. Means comparison of *PC* by *TEST* and *FUN* (Dataset E6).

TEST	**N**	δ_M	***PC* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
AE1	912	0.66	85.86	95.76	97.42
CCE1	768	0.70	83.97	97.06	97.10
CTE1	756	0.71	91.04	96.97	97.64

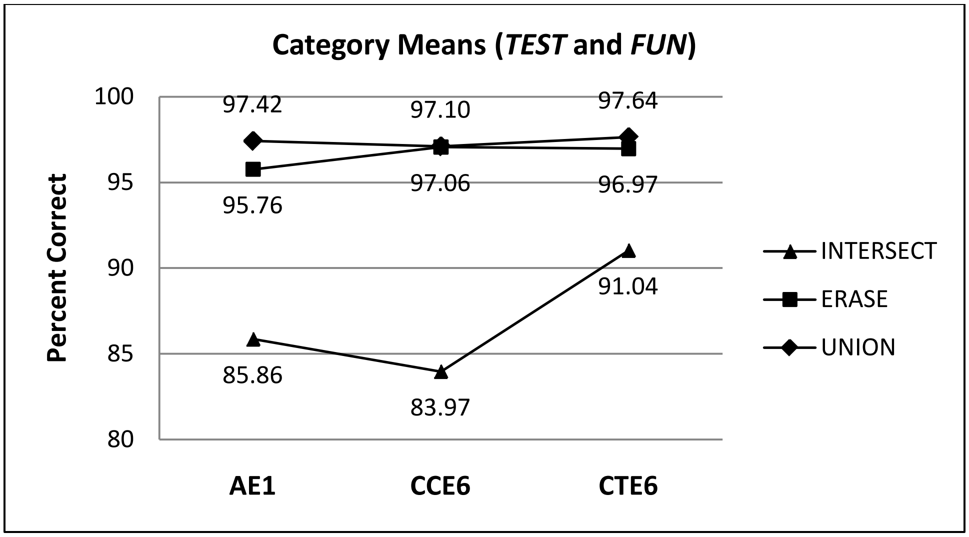


Figure 47. The two-way interaction effect on *PC* for *TEST* and *FUN* (Dataset E6).

Table 35. Means comparison of *RT* by *TEST* and *FUN* (Dataset E6).

TEST	**N**	δ_M	***RT* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
AE1	912	54.97	4675.02	3394.22	3133.94
CCE1	768	58.59	3986.81	3537.86	3485.85
CTE1	756	59.03	2537.59	2214.18	2239.03

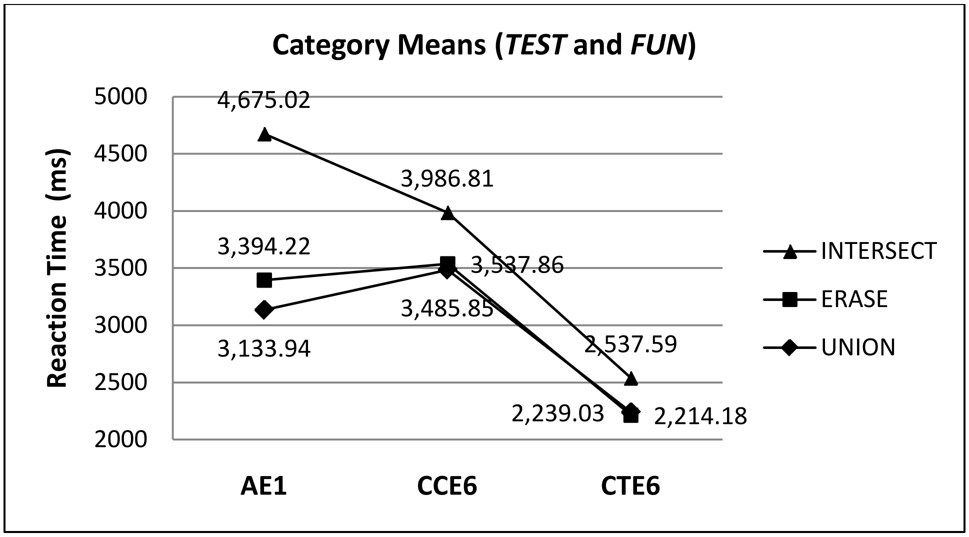


Figure 48. The two-way interaction effect on *RT* for *TEST* and *FUN* (Dataset E6).

Statistical significance was also found for the *TEST* and *MAN* two-way interaction with respect to *PC* (Table 26). Each group exhibited a specific break from the other groups with respect to a particular manipulation (Table 36). The adult group scored markedly lower on questions pertaining to the output manipulation. The child control group outperformed the other groups on questions of function manipulation. The child control group scored poorly compared to the other groups for the input manipulations. While outperforming the adult group in three of the four manipulations, the child test group recorded its lowest mean value for the second input manipulation (Figure 49).

Table 36. Means comparison of *PC* by *TEST* and *MAN* (Dataset E6).

TEST	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
AE1	912	0.76	93.90	94.28	93.83	89.95
CCE1	768	0.81	91.00	90.69	96.58	92.58
CTE1	756	0.81	95.20	92.50	97.05	96.12

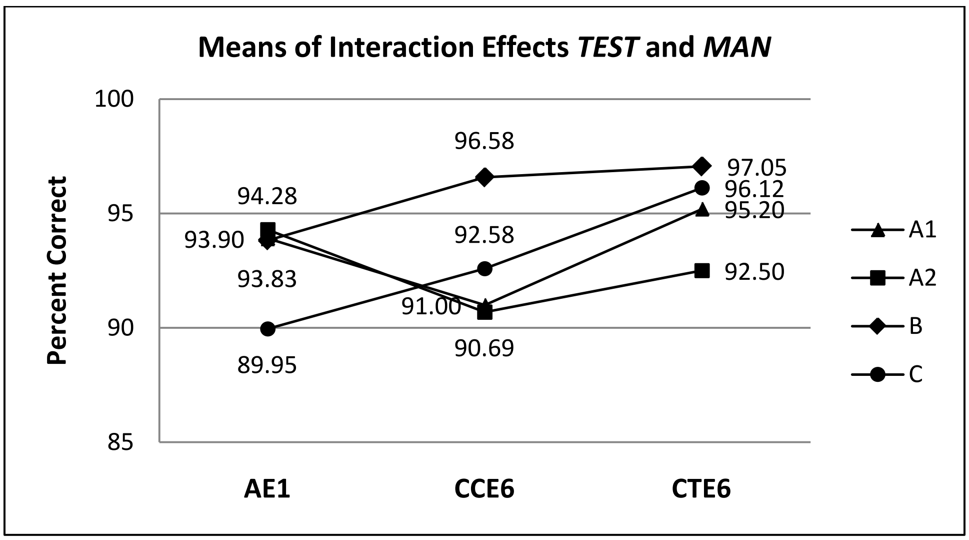


Figure 49. The two-way interaction effect on *PC* for *TEST* and *MAN* (Dataset E6).

Statistical significance, with respect to *PC* (Table 26) and *RT* (Table 27), was found for the two-way interaction between *TEST* and *SEX*. Males within the adult group demonstrated distinctively higher *PC* scores than their in-group females, while females of the child test group scored higher than their male counterparts (Table 37, Figure 50). With respect to *RT*, males recorded lower values than females within the adult group, while females responded faster within the child control group (Table 38, Figure 51).

Table 37. Means comparison of *PC* by *TEST* and *SEX* (Dataset E6).

TEST	**N**	***PC* by *SEX***			
		Male	δ_M	**Female**	δ_M
AE1	912	94.19	0.59	91.83	0.48
CCE1	768	92.63	0.56	92.80	0.58
CTE1	756	94.09	0.57	96.34	0.58

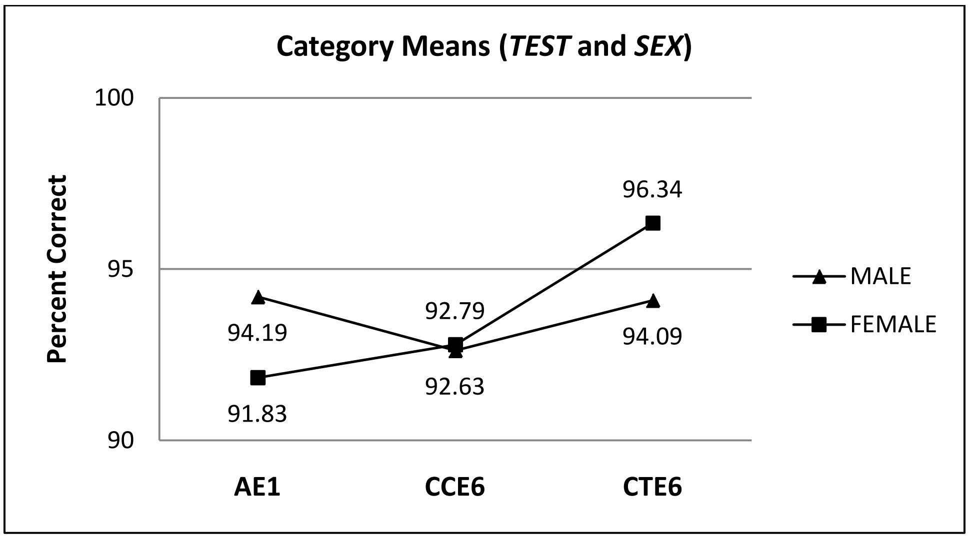


Figure 50. The two-way interaction effect on *PC* for *TEST* and *SEX* (Dataset E6).

Table 38. Means comparison of *RT* by *TEST* and *SEX* (Dataset E6).

TEST	**N**	***RT* by *SEX***			
		Male	δ_M	**Female**	δ_M
AE1	912	3428.24	49.38	4040.55	39.88
CCE1	768	3823.39	47.08	3516.96	48.58
CTE1	756	2360.99	47.81	2299.54	48.58

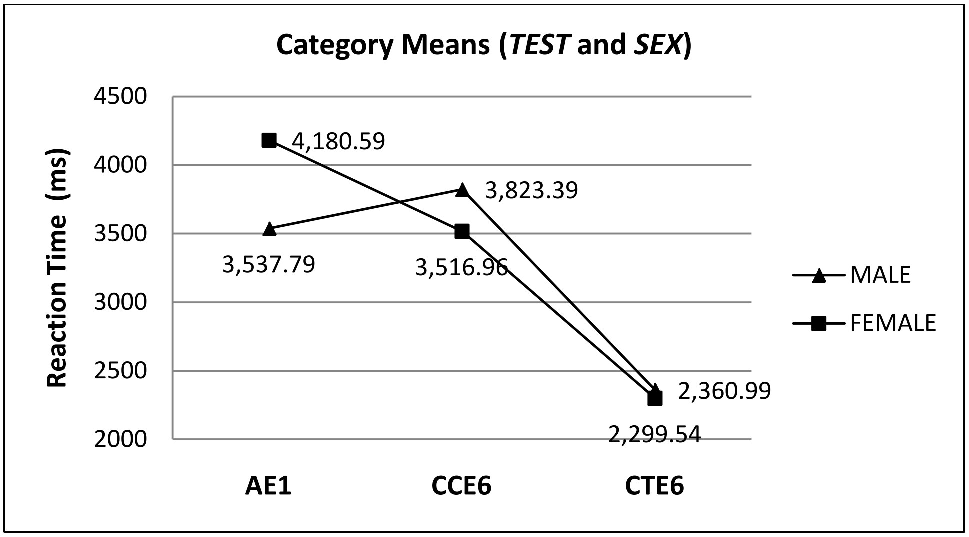


Figure 51. The two-way interaction effect on *RT* for *TEST* and *SEX* (Dataset E6).

Statistical significance was found for the two-way interaction between *FUN* and *MAN* with respect to *PC* (Table 26) and *RT* (Table 27). An interesting pattern was again observed on questions pertaining to the B and C manipulations. *PC* values were lower for these manipulations than those recorded for ERASE and UNION functions, but were highest within the INTERSECT function (Table 39, Figure 52). *RT* values were found to be more than a half-second lower for the B and C manipulations with respect to the INTERSECT function (Table 40, Figure 53).

Table 39. Means comparison of *PC* by *FUN* and *MAN* (Dataset E6).

FUN	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	812	0.79	83.81	81.85	93.87	88.28
ERASE	812	0.79	98.37	97.92	96.86	93.23
UNION	812	0.79	97.99	97.70	96.72	97.14

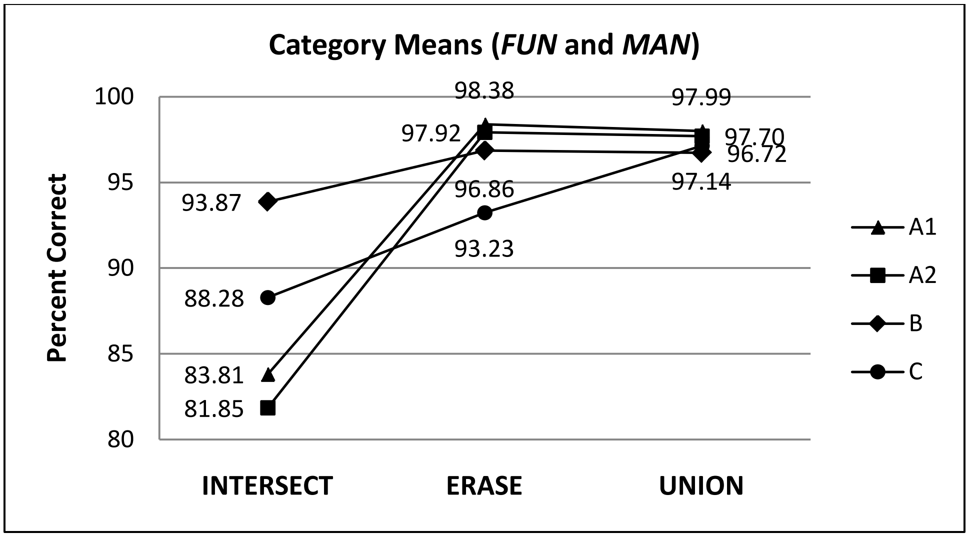


Figure 52. The two-way interaction effect on *PC* for *FUN* and *MAN* (Dataset E6).

Table 40. Means comparison of *RT* by *FUN* and *MAN* (Dataset E6).

FUN	**N**	δ_M	***RT* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	812	66.46	3991.33	4097.38	3455.85	3388.00
ERASE	812	66.46	3132.55	3199.17	2803.34	3059.97
UNION	812	66.46	2989.21	3022.25	2829.63	2970.66

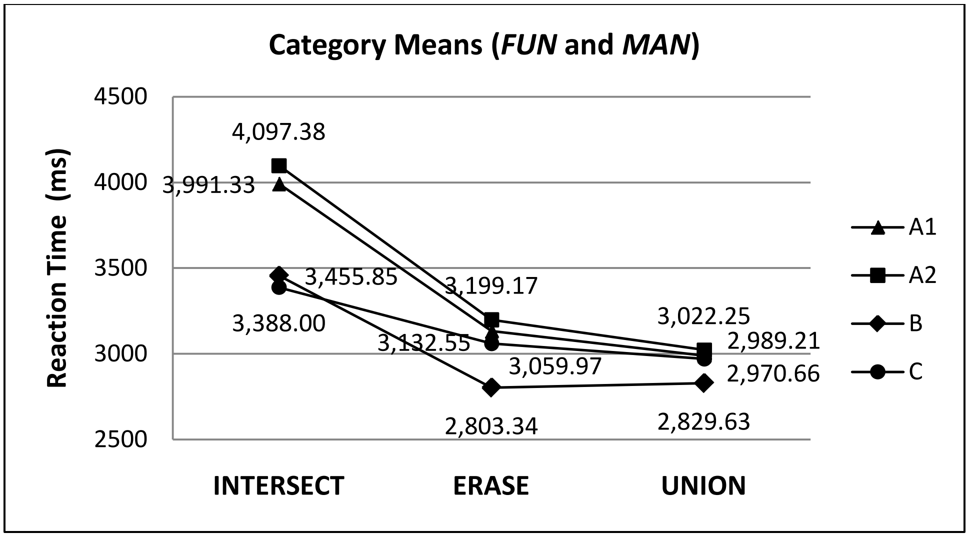


Figure 53. The two-way interaction effect on *RT* for *FUN* and *MAN* (Dataset E6).

A three-way interaction was found to be significant in *PC* for *TEST* and *FUN* and *MAN*. A comparison of *PC* values between the child control group and the child test group specific to the INTERSECT function of A1 and A2 manipulations revealed significant differences. Child control group observations of (75.16) and (76.13) for the A1 and A2 manipulation of INTERSECT respectively were far lower than (90.14) and (83.00) observed for the child test group.

Another three-way interaction was found to be significant in *PC* for *TEST* and *FUN* and *SEX*. Females of the child test group recorded the highest *PC* values across all functions for every group combination. The INTERSECT (91.37) value was the only observation above 91 percent, and the ERASE (98.71) and UNION (98.95) values were the only observations above 98 percent during the entire experiment.

Discussion of Interaction Effects

Interaction analysis between *TEST* and *FUN* indicated results similar to those found during Dataset E1 analysis. The INTERSECT function was again significantly more difficult for the child control group to perform than other functions; however, the adult group took longer to answer these questions than the other groups. The child control group exhibited a much lower *RT* than the adult group with respect to the INTERSECT function. These results were again expected in accordance with the results of the univariate analysis. The observation that middle schoolers continued to experience trouble with the INTERSECT function reconfirms results of previous studies pinpointing the map overlay intersect concept as more difficult than others (Albert and Golledge, 1999). Of particular interest was the observation that the child test group recorded a higher *PC* mean than the other groups and a *RT* mean below that of any other function for any other group. The exceptional performance of the child test group during epoch 6 compared to the other groups indicates that these subjects had at the very least learned how to master the test.

The *TEST* and *MAN* interaction analysis followed earlier univariate analysis observations in that the highest values of *PC* were recorded by the child test group, and the B manipulation. In fact, the child test group means for A1, B, and C were higher than those of any other variable combination. Following their young adolescent schoolmates, the child control group also recorded a very high *PC* mean for the B manipulation, well above that of the adult group. These results confirm earlier indications that while the B manipulation may prove difficult under initial introduction, it may be the easiest to acknowledge once the concept is understood.

Analysis of *TEST* and *SEX* interaction again revealed that adult males recorded more correct answers in less time than adult females. In general, males performed fairly even across the groups with respect to *PC*, with child control group males performing slightly lower than the others. Females of the child test group scored higher *PC* values than any other group combination. Child test group males and females recorded similar *RT* means with each other and registered values very much faster than the other groups. Therefore, child test group females were able to decrease their *RT* without sacrificing *PC* when compared with the child test group males.

The interaction between *FUN* and *MAN* continued the same trend observed within Dataset E1. Regardless of manipulation, all questions involving INTERSECT had high values of *RT* and low values of *PC*. Again, the manipulations A1 and A2 represented values at the extreme. These results were again expected as previous studies (Albert & Golledge, 1999; Battersby et al., 2006) and the univariate analysis found similar results regarding the INTERSECT function. The B manipulation continued to correspond with the highest *PC* value when coupled with the INTERSECT function and the lowest *RT* value when combined with the ERASE and UNION functions. This may continue to be explained by the inherent uniqueness of resultant map overlay intersect outputs when compared with those of the other functions.

The three-way interaction between *TEST* and *FUN* and *MAN* for *PC* revealed the importance of practice through repeated instruction and testing on the ability to learn map overlay concepts, specifically INTERSECT. Throughout the experiment, questions pertaining to INTERSECT consistently produced the lowest *PC* values. Similarly, questions pertaining to the input manipulations of A1 and A2 produced low values of *PC*. The observation that the child test group was significantly more accurate for these tasks during the final epoch than the child control group illustrates that learning occurred.

The three-way interaction between *TEST* and *FUN* and *SEX* for *PC* also supported the idea that repeated instruction and practice could facilitate learning and increase performance to the level of experts or even higher. Child test group females exhibited lower values of *PC* than males during the first epoch. Epoch 6 observations in which females of this group recorded the highest values for all conditions of *FUN* throughout the experiment reveal that practice can both increase performance to the level of experts and close any observed gap between the sexes.

Dataset C16

The results of the MANOVA indicated that the model was statistically significant at $\alpha = 0.05$ (F=177020.945, P>F=0.000). Main effects *TEST*, *FUN*, *MAN*, and *SEX* were significant. Several interactions were also significant. These interactions included, *TEST**FUN*, *TEST*MAN*, *TEST*SEX*, *FUN*MAN*, and *TEST*FUN*MAN* (Table 41).

Table 41. Summary of MANOVA analysis based on Pillai's Trace (Dataset C16).

Main Effect	F-Score	Probability > F	Observed Power
TEST	228.6	0.000	1.00
FUN	213.5	0.000	1.00
MAN	19.1	0.000	1.00
SEX	26.3	0.000	1.00
Interaction Effect			
TEST and *FUN*	17.8	0.000	1.00
TEST and *MAN*	3.5	0.000	1.00
TEST and *SEX*	4.7	0.000	0.99
FUN and *MAN*	13.1	0.000	1.00
TEST and *FUN* and *MAN*	2.3	0.000	1.00

The univariate test of between-subjects effects for the dependent variable *PC* showed significance for the overall model at $\alpha = 0.05$ (F=1843.968, P>F=0.000). Main effects *TEST*, *FUN*, and *MAN* were found to be significant. The interactions *TEST**FUN*, *TEST*MAN*, *TEST*SEX*, *FUN*MAN*, and *TEST*FUN*MAN* were also significant (Table 42).

Table 42. Summary of univariate (*PC*) analysis based on Type III Sum of Squares (Dataset C16).

Main Effect	F-Score	Probability > F	Observed Power
TEST	22.2	0.000	1.00
FUN	311.8	0.000	1.00
MAN	2.8	0.036	0.69
Interaction Effect			
TEST and *FUN*	10.5	0.000	1.00
TEST and *MAN*	6.3	0.000	1.00
TEST and *SEX*	4.2	0.006	0.86
FUN and *MAN*	23.0	0.000	1.00
TEST and *FUN* and *MAN*	3.3	0.000	1.00

The univariate test of between-subjects effects for the dependent variable *RT* showed significance for the overall model at α = 0.05 (F=404.433, P>F=0.000). Significance was found for main effects *TEST*, *FUN*, *MAN*, and *SEX*. The interactions *TEST**FUN*, *TEST**SEX*, and *FUN**MAN* were also significant (Table 43).

Table 43. Summary of univariate (*RT*) analysis based on Type III Sum of Squares (Dataset C16).

Main Effect	F-Score	Probability > F	Observed Power
TEST	587.1	0.000	1.00
FUN	228.1	0.000	1.00
MAN	37.2	0.000	1.00
SEX	52.1	0.000	1.00
Interaction Effect			
TEST and *FUN*	27.9	0.000	1.00
TEST and *SEX*	4.6	0.003	0.89
FUN and *MAN*	8.8	0.000	1.00

Analysis of Category Means

A range of means test was performed to further examine category means for the variable *TEST*. The child test group epoch 6 (95.20) recorded a significantly higher *PC* mean than the child control group epoch 6 (92.71), the child test group epoch 1 (92.63), and the child control group epoch 1 (90.09) (Table 44, Figure 54). The child test group epoch 6 (2336.48) also recorded the significantly fastest *RT*, followed by the child test group epoch 1 (3518.33), the child control group epoch 6 (3703.82), and then the child control group epoch 1 (4519.84) (Table 45, Figure 55).

Table 44. Means comparison of *PC* by *TEST* based on S-N-K (Dataset C16).

TEST	**N**	δ_M	***PC*** Subset 1	2	3
CCE1	768	0.59	90.09		
CTE1	756	0.56		92.63	
CCE6	768	0.46		92.71	
CTE6	756	0.38			95.20
Sig.			1	0.903	1

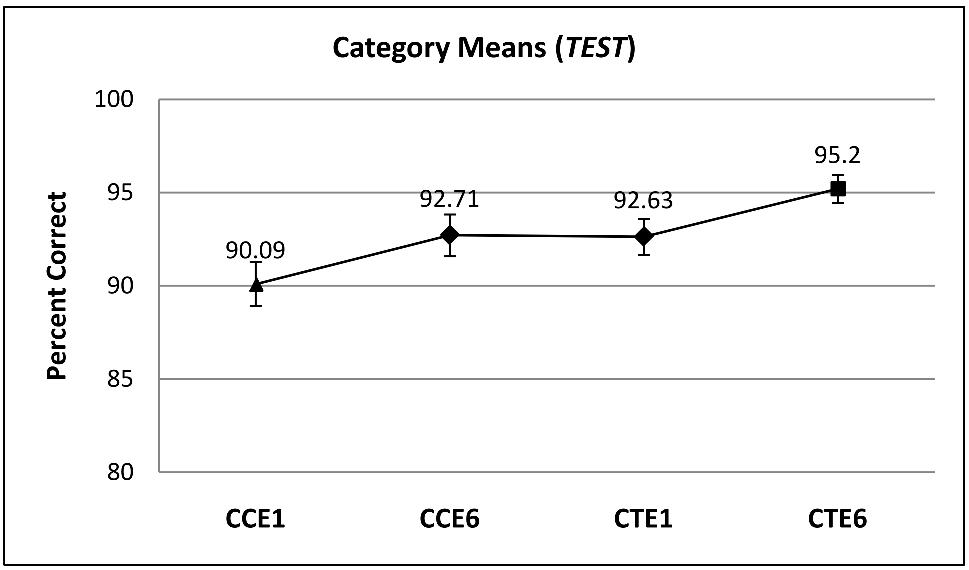


Figure 54. *PC* by *TEST* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Table 45. Means comparison of *RT* by *TEST* based on S-N-K (Dataset C16).

TEST	**N**	δ_M	***RT***			
			Subset			
			1	**2**	**3**	
CCE1	768	49.71	4519.84			
CCE6	768	45.10		3703.82		
CTE1	756	43.74			3518.33	
CTE6	756	23.61				2336.48
Sig.			1	1	1	1

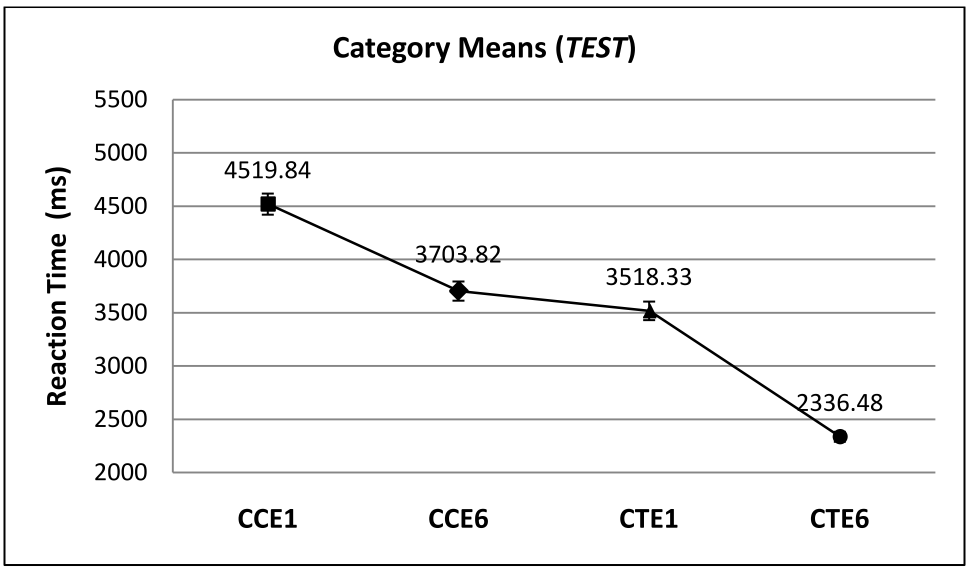


Figure 55. *RT* by *TEST* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Category means and their level of significance with respect to *PC* and *RT* for the variable *FUN* are illustrated in Table 46 and Table 47. Significant differences in *PC* were found between the category means for INTERSECT (84.83) which yielded the lowest number of correct answers and both ERASE (96.38) and UNION (96.73) (Figure 56). Consistent with the results of *PC*, INTERSECT questions represented the lowest performance values of *RT*. As with *PC*, significant differences in *RT* were found between INTERSECT (4084.01) and both ERASE (3255.29), and UNION (3233.54) (Figure 57).

Table 46. Means comparison of *PC* by *FUN* based on S-N-K (Dataset C16).

FUN	**N**	δ_M	***PC*** Subset 1	Subset 2
INTERSECT	1016	0.58	84.83	
ERASE	1016	0.27		96.38
UNION	1016	0.29		96.73
Sig.			1	0.513

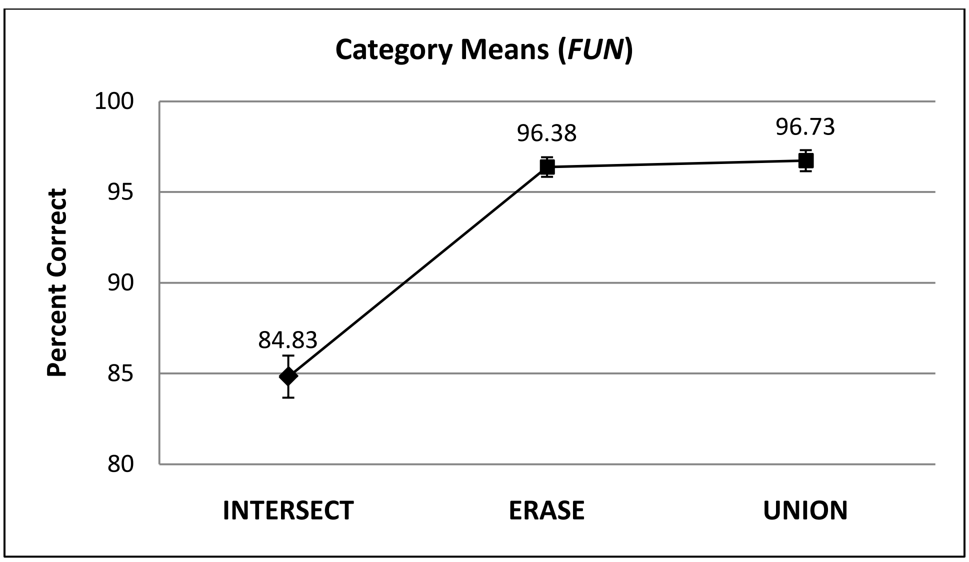


Figure 56. *PC* by *FUN* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Table 47. Means comparison of *RT* by *FUN* based on S-N-K (Dataset C16).

FUN	**N**	δ_M	***RT*** **Subset** 1	***RT*** **Subset** 2
INTERSECT	1016	51.01	4084.01	
ERASE	1016	35.37		3255.29
UNION	1016	37.70		3233.54
Sig.			1	0.632

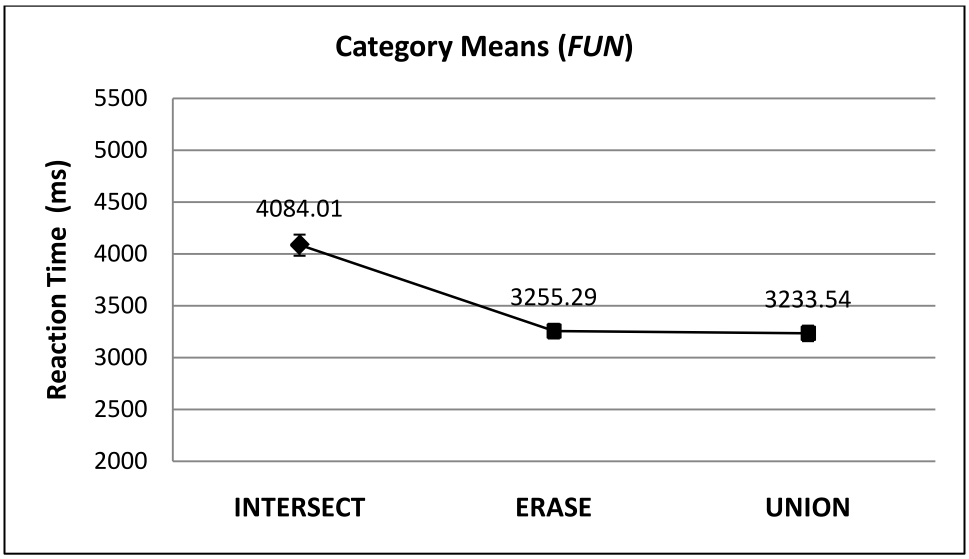


Figure 57. *RT* by *FUN* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Significant differences in the category means of *MAN* with respect to *PC* were also found (Table 48). The mean of spatial manipulation B was significantly different from the means of A2. The highest percent correct was recorded when solving for the function (93.58) manipulation while the first input (92.64), output (92.57), and second input (91.80) manipulations elicited lower accuracy (Figure 58). Significant differences in *RT* were found between each of the manipulations with the exception of A1 and A2, which were not significantly different than one another (Table 49). Subjects answered the function (3262.35) manipulation fastest, followed by the output (3411.25) manipulation, and then the first (3692.81) and second (3730.71) input manipulations (Figure 59).

Table 48. Means comparison of *PC* by *MAN* based on S-N-K (Dataset C16).

MAN	**N**	δ_M	***PC***	
			Subset	
			1	**2**
A2	762	0.46	91.80	
C	762	0.50	92.57	92.57
A1	762	0.52	92.64	92.64
B	762	0.55		93.58
Sig.			0.371	0.238

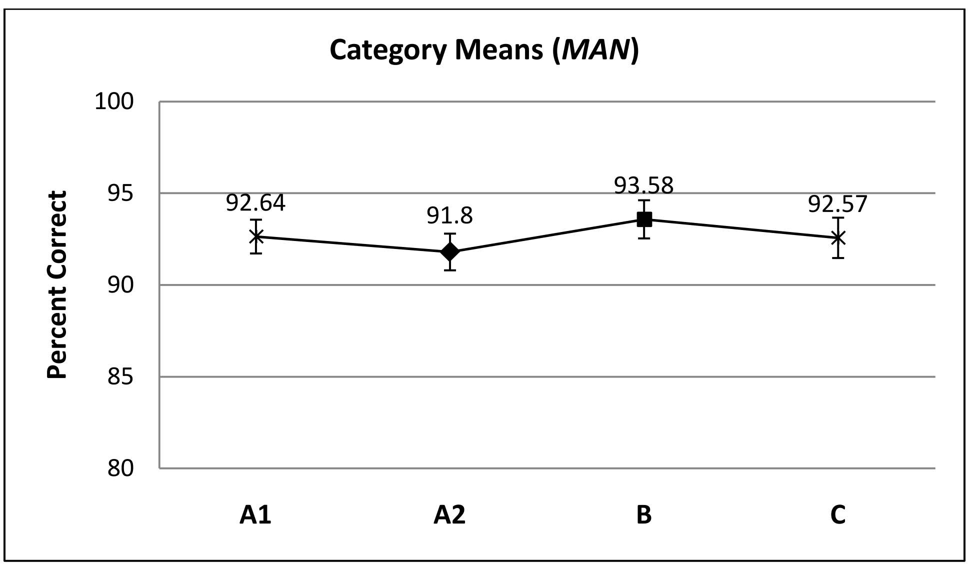


Figure 58. *PC* by *MAN* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Table 49. Means comparison of *RT* by *MAN* based on S-N-K (Dataset C16).

MAN	**N**	δ_M	***RT***		
			Subset		
			1	**2**	**3**
B	762	51.23	3262.35		
C	762	48.11		3411.25	
A1	762	51.17			3692.81
A2	762	51.95			3730.71
Sig.			1	1	0.470

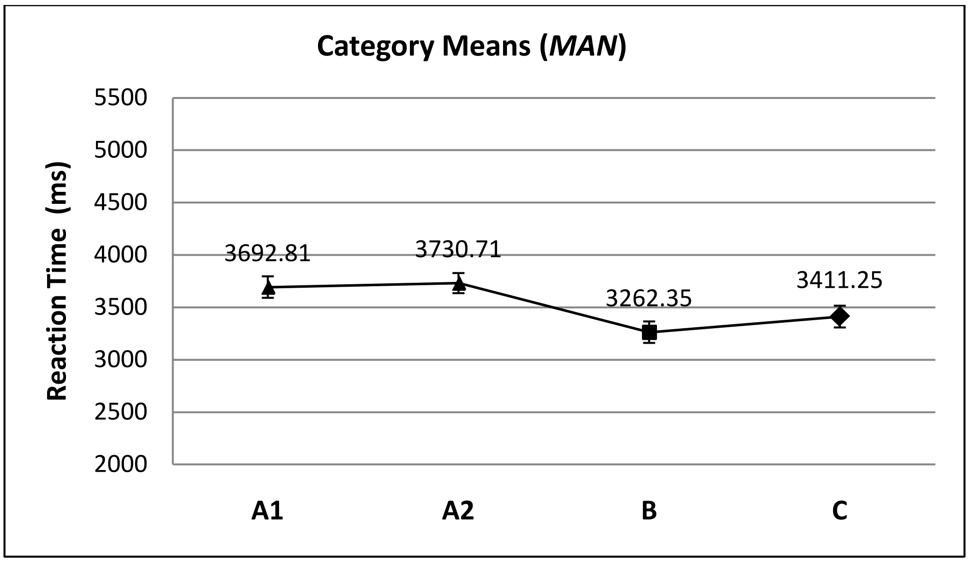


Figure 59. *RT* by *MAN* (Dataset C16). Dissimilar point symbols designate significantly different category means.

Discussion of Category Means

Dataset C16 is comprised of the initial (epoch 1) and final (epoch 6) test data for each of the young adolescent groups; child control group (CCE1 and CCE6) and child test group (CTE1 and CTE6). Univariate analysis found significant differences in *PC* means of *TEST* between CTE6 and each of the other groups. CTE6 exhibited a higher *PC* than the other groups. There was also a significant difference for *RT* observed between the groups. CTE6 again exhibited significantly higher performance values than the other groups. CTE6 exhibited the lowest times followed next by CTE1, CCE6 and then CCE1. These results indicate that both of the young adolescent groups significantly increased performance of *PC* and *RT* for the E6 test over the E1 test, and the child test group consistently exceeded that of the child control group. Again, it should be noted that the performance of the child control group increased after having received no experimental instruction other than that of the pre-test. The E6 test marked the second experience these subjects had with the material. The tests from epoch 1 and 6 contained unique questions, which leads to the question of whether the simple act of taking a second test proved to enhance the performance of the child control group subjects.

The INTERSECT function showed significantly lower values of *PC* and significantly higher values of *RT* across these groups. UNION and ERASE functions showed no significant differences in performance between each other. The consistency of these results with those of Datasets E1 and E6 illustrate that struggles with INTERSECT were consistent throughout the experiment for the young adolescents regardless of group (control, test, expert).

Examination of significance of *PC* within *MAN* illustrates that the removal of the adult group data (AE1) results in a tighter grouping of means across the categories of *MAN*. A significant difference was only observed between B and A2. Results of Datasets E1 and E6, which incorporated AE1, revealed significance between both of the input and output manipulations. Young adolescents across epochs 1 and 6 did not show significant differences between any manipulations with regard to either A1 or C. The B manipulation recorded significantly lower *RT* values than C which in turn was significantly lower than the A1 and A2 manipulations. Again, the higher performance by subjects with respect to the B manipulation may infer that different cognitive processes took place while solving for the types of manipulations within this study. Overall, young adolescents demonstrated a greater ability to solve for the manipulation than any other.

Analysis of Interaction Effects

Statistical significance was found for the two-way interaction between *TEST* and *FUN* with respect to *PC* (Table 42) and *RT* (Table 43). Across both epochs, the child control, and child test group each had distinctively lower *PC* (Table 50) and higher *RT* (Table 51) values for the INTERSECT function than the ERASE and UNION functions. With the exception of the child test group epoch 6, each group recorded INTERSECT values of *PC* around 10 percent lower (Figure 60) and *RT* values up to 1.5 seconds longer (Figure 61) than the other functions.

Table 50. Means comparison of *PC* by *TEST* and *FUN* (Dataset C16).

TEST	**N**	δ_M	***PC* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
CCE1	768	0.76	79.10	95.40	95.84
CCE6	768	0.76	83.97	97.06	97.10
CTE1	756	0.77	85.38	96.14	96.42
CTE6	756	0.77	91.04	96.97	97.64

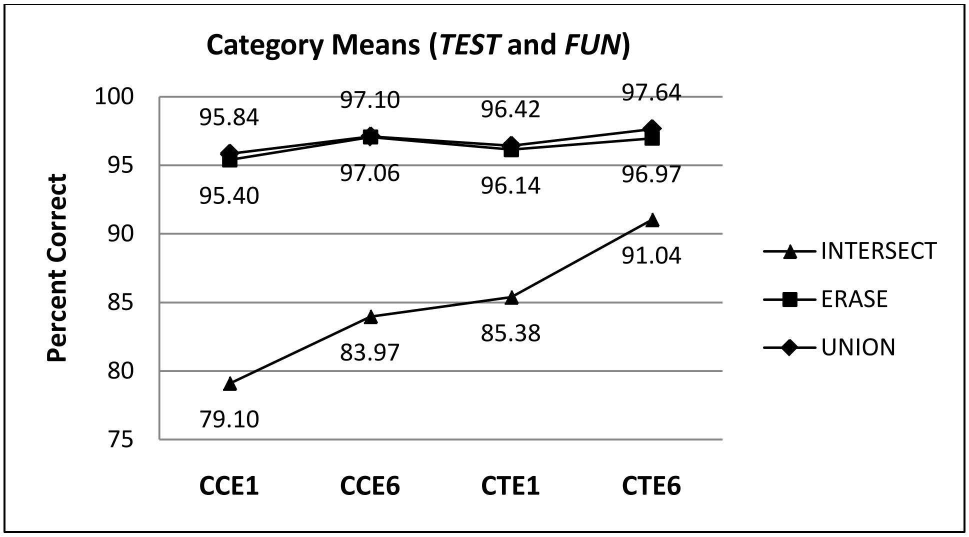


Figure 60. The two-way interaction effect on *PC* for *TEST* and *FUN* (Dataset C16).

Table 51. Means comparison of *RT* by *TEST* and *FUN* (Dataset C16).

TEST	**N**	δ_M	***RT* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
CCE1	768	64.01	5592.78	3915.14	4040.53
CCE6	768	64.01	4034.56	3548.45	3513.55
CTE1	756	64.49	4136.21	3315.11	3114.35
CTE6	756	64.49	2549.53	2217.61	2240.67

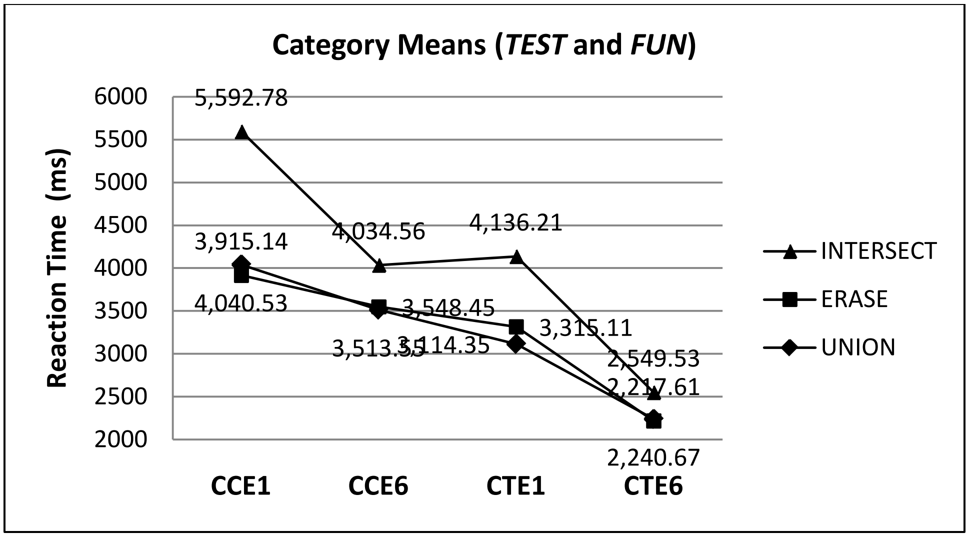


Figure 61. The two-way interaction effect on *RT* for *TEST* and *FUN* (Dataset C16).

Statistical significance was also found for the two-way interaction of *TEST* and *MAN* with respect to *PC* (Table 42). Specific differences were observed for each group with respect to a single manipulation (Table 52). While the *PC* values of the child control group during epoch 6 were similar to those of epoch 1 for the child test group, the B manipulation score of the child control group reached the very high level attained by the child test group during epoch 6. With the exception of the epoch 6 child control group B manipulation, the *PC* values achieved by the child control group during epoch 6 were level with or higher than any other *TEST* and *MAN* combination of the experiment (Figure 62).

Table 52. Means comparison of *PC* by *TEST* and *MAN* (Dataset C16).

TEST	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
CCE1	768	0.88	91.58	92.03	87.10	89.76
CCE6	768	0.88	91.00	90.69	96.58	92.58
CTE1	756	0.89	92.84	92.02	93.79	91.93
CTE6	756	0.89	95.20	92.50	97.05	96.12

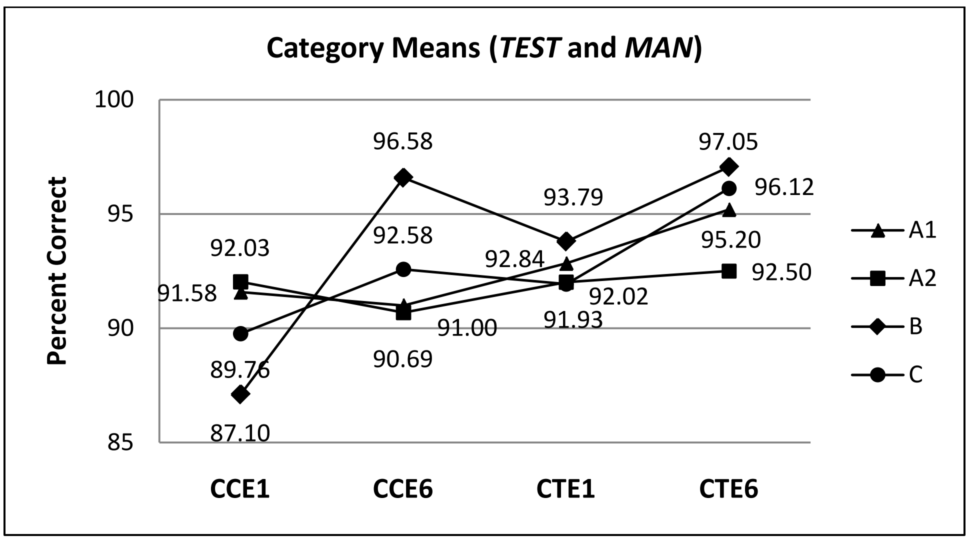


Figure 62. The two-way interaction effect on *PC* for *TEST* and *MAN* (Dataset C16).

Statistical significance, with respect to *PC* (Table 42) and *RT* (Table 43), was found for the two-way interaction between *TEST* and *SEX*. Males within the child control group performed at a level with females during epoch 6 after demonstrating lower performance during epoch 1. Females within the child test group demonstrated a very distinctive increase in *PC* scores from epoch 1 to epoch 6 (Table 53, Figure 63). With respect to *RT*, females consistently recorded lower values than males across all groups (Table 54, Figure 64).

Table 53. Means comparison of *PC* by *TEST* and *SEX* (Dataset C16).

TEST	**N**	***PC* by *SEX***			
		Male	δ_M	**Female**	δ_M
CCE1	768	89.29	0.61	90.94	0.63
CCE6	768	92.63	0.61	92.80	0.63
CTE1	756	93.55	0.63	91.75	0.62
CTE6	756	94.09	0.63	96.34	0.62

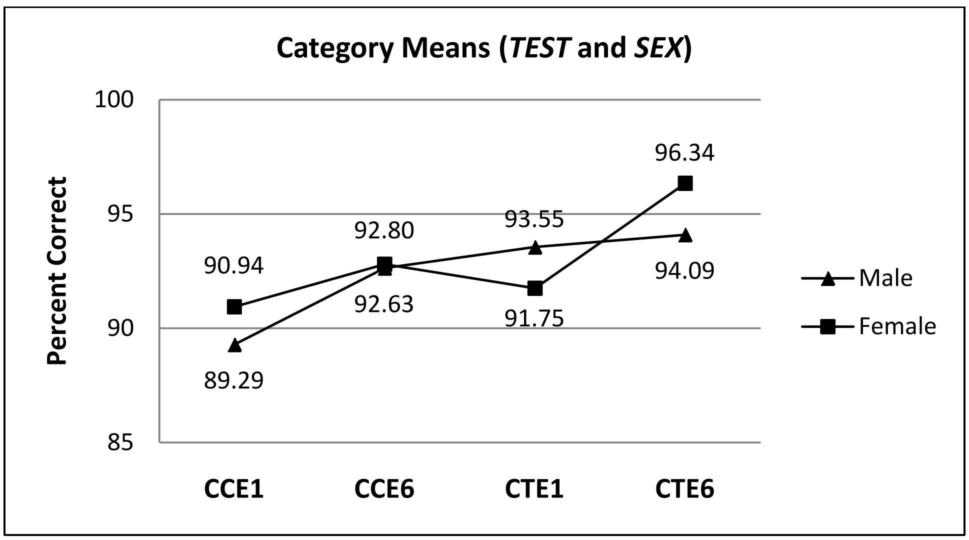


Figure 63. The two-way interaction effect on *PC* for *TEST* and *SEX* (Dataset C16).

Table 54. Means comparison of *RT* by *TEST* and *SEX* (Dataset C16).

TEST	**N**	***RT* by *SEX***			
		Male	δ_M	**Female**	δ_M
CCE1	768	4634.16	51.44	4398.14	53.07
CCE6	768	3857.89	51.44	3539.82	53.07
CTE1	756	3746.12	53.07	3297.65	52.24
CTE6	756	2369.98	53.07	2301.89	52.24

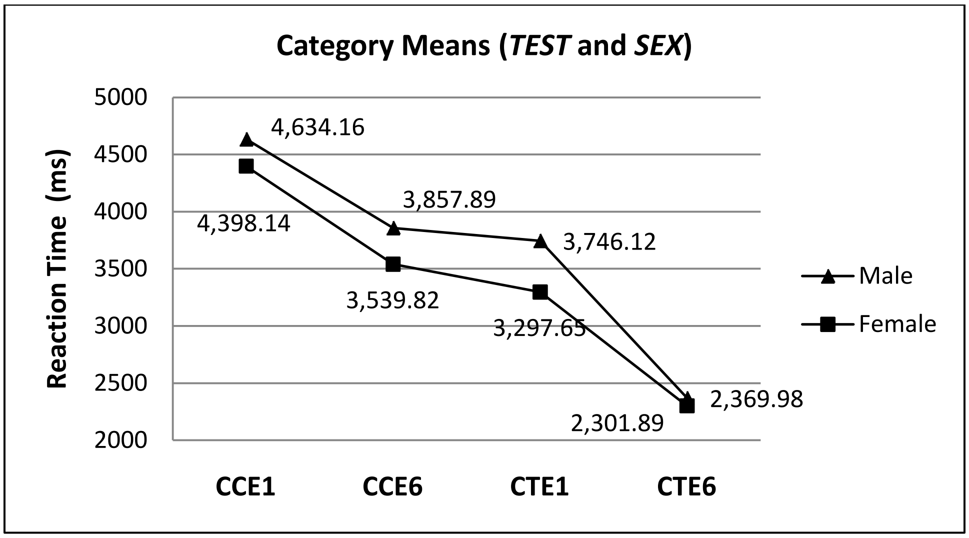


Figure 64. The two-way interaction effect on *RT* for *TEST* and *SEX* (Dataset C16).

Statistical significance was found for the two-way interaction between *FUN* and *MAN* with respect to *PC* (Table 42) and *RT* (Table 43). Young adolescents demonstrated lower performance in *PC* (Table 55) and *RT* (Table 56) on questions pertaining to either of the A1 and A2 manipulations and the INTERSECT function. An interesting pattern was again observed on questions pertaining to the B and C manipulations. *PC* values were lower (Figure 65) and *RT* values were higher (Figure 66) for these manipulations than those recorded for any other *FUN* and *MAN* combination.

Table 55. Means comparison of *PC* by *FUN* and *MAN* (Dataset C16).

FUN	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	1016	0.77	81.98	80.06	90.66	86.80
ERASE	1016	0.77	98.17	97.79	95.54	94.08
UNION	1016	0.77	97.82	97.57	94.69	96.92

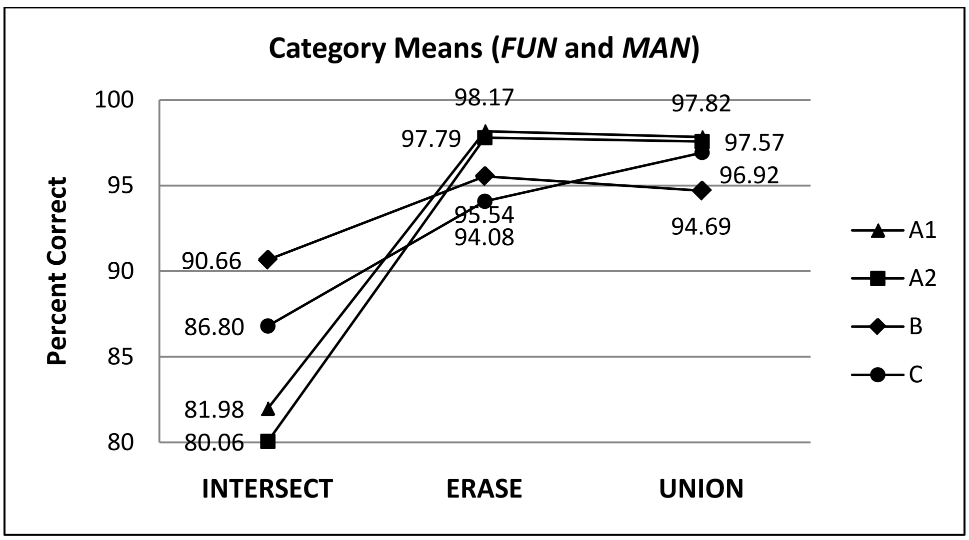


Figure 65. The two-way interaction effect on *PC* for *FUN* and *MAN* (Dataset C16).

Table 56. Means comparison of *RT* by *FUN* and *MAN* (Dataset C16).

FUN	**N**	δ_M	***RT* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	1016	64.25	4381.54	4461.91	3755.54	3714.09
ERASE	1016	64.25	3406.90	3458.96	2943.16	3187.30
UNION	1016	64.25	3269.21	3259.89	3068.52	3311.46

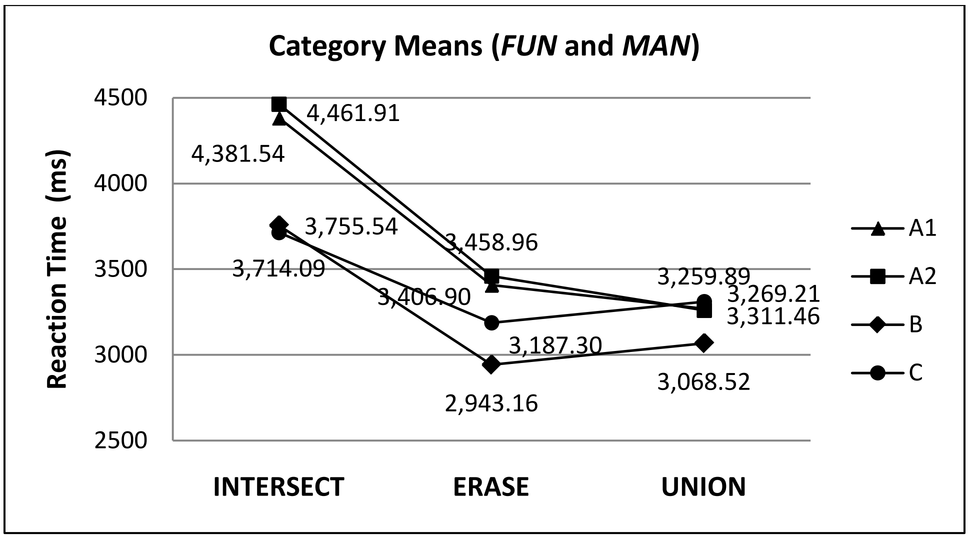


Figure 66. The two-way interaction effect on *RT* for *FUN* and *MAN* (Dataset C16).

A three-way interaction was found to be significant in *PC* for *TEST* and *FUN* and *MAN*. A comparison of *PC* values between epoch 1 and epoch 6 for the child test group specific to the INTERSECT function of all conditions of *MAN* revealed where significant differences occurred. Child test group epoch 6 observations of A1 (90.14), A2 (83.00), B (95.42), and C (95.59) for the INTERSECT function reveal where improvements in performance occurred when compared to the epoch 1 observations of (83.29), (83.35), (90.67), and (84.21) respectively.

Discussion of Interaction Effects

Interaction analysis between *TEST* and *FUN* indicated that the INTERSECT function was significantly more difficult for the young adolescents to perform than other functions. The child control group and the child test group both significantly improved performance on this and the other functions from epoch 1 to epoch 6; however, the child test group appeared to close the performance gap of the functions between the epochs. Their *PC* values of INTERSECT during epoch 6 were near those of ERASE and UNION. No significant difference in *RT* was observed between any of the functions during epoch 6 for the child test group. Compared to the child control group, the exceptional performance of the child test group during epoch 6 indicates that these subjects gained a superior level of understanding of the map overlay concept.

The *TEST* and *MAN* interaction analysis showed two interesting observations. First, the child control group exhibited a drastic increase in *PC* for the B manipulation from epoch 1 to epoch 6. A similar, albeit less pronounced increase in performance was observed for the C manipulation. These observations coupled with the lack of an overall increase in significance of the combined other manipulations reveal that these subjects may have experienced some degree of learning between epochs. It would be expected that any additional familiarity with the test taking procedure, such as taking the test a second time, might result in increased performance; however such an increase would be expected across all manipulations. Simply learning how to take the test does not account for the increases in solving for the specific manipulations of B and C. These results again confirm earlier indications that the ability to solve for the B manipulation may be the best indicator that the concept is understood. Second, while the overall pattern of results for both of the child control groups and epoch 1 of the child test group are similar, the epoch 6 results of the child test group are superior to all other groups. The practice of engaging in repeated instruction and testing may have played a significant role in the overall exceptional performance of the child test group over the child control group.

Analysis of *TEST* and *SEX* interaction revealed that child test group females experienced the most gains throughout the experiment. While the child test group males recorded higher *PC* values than male and females of the child control group, the child test group females recorded a significant increase from epoch 1 to epoch 6. Within the child test group, males performed significantly higher than females during epoch 1, but these results were reversed during epoch 6. These drastic improvements in the performance of females follow those observed in other similar studies of spatial abilities and practice (Cherney, 2008). The females of each group also recorded the lowest *RT* values during each epoch. Also of note was the observation that the child test group males and females recorded nearly identical *RT* means during epoch 6 and registered values very much faster than any other group. Overall, females engaged in repeated practice were able to significantly increase performance of *PC* and *RT* above those increases demonstrated by males.

The interaction between *FUN* and *MAN* continued the same trend observed within Datasets E1 and E6. Regardless of manipulation, all questions involving INTERSECT had high values of *RT* and low values of *PC*. The manipulations A1 and A2 continued to represent values at the extreme. These results were in line with those of Dataset E1 and

E6 univariate analysis as well as results from earlier studies (Albert & Golledge, 1999; Battersby et al., 2006). The B manipulation also continued to correspond with the highest *PC* value when coupled with the INTERSECT function and the lowest *RT* value when combined with the ERASE and UNION functions. Across all age groups and experience levels within this study, the complications inherent to the INTERSECT function and the A1 and A2 manipulations are apparent.

The three-way interaction observed for Dataset C16 between *TEST* and *FUN* and *MAN* for *PC* revealed that difficulties surrounding the INTERSECT function were significantly addressed for all manipulations except A2. The A1, B, and C manipulations each recorded 5 percent or greater increases in *PC* between epoch 1 and epoch 6. These observations show that learning of the function, output, and inputs can be accomplished through repeated practice. The specific observation of the lack of a significant increase in *PC* for the A2 manipulation is likely due to the location of this condition within the map overlay formula. Located in the center of the formula, subjects must visually compare both the beginning and end of the formula in order to solve for the missing shape centered within the formula. When combined with the request to answer questions as quickly as possible, this additional search may be responsible for the observed continued difficulties for this manipulation.

Dataset CT

Repeated measures analyses for both *PC* and *RT* were conducted against the child test group throughout all epochs. Mauchly's test indicated that the assumption of sphericity had been violated for the dependent variable *PC*, $X^2(14)=498.861$, $p<0.05$, therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity (ε=0.788). The results show that the model was statistically significant at $\alpha = 0.05$ (F=9.899, P>F=0.000). Mauchly's test indicated that the assumption of sphericity had also been violated for the dependent variable *RT*, $X^2(14)=730.024$, $p<0.05$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε=0.690). The results show that the model was statistically significant at $\alpha = 0.05$ (F=365.897, P>F=0.000).

The univariate test of between-subjects effects for the dependent variable *PC* showed significance for the overall model at $\alpha = 0.05$ (F=110688.342, P>F=0.000). Main effects *FUN* and *MAN* were found to be significant. The interaction *FUN***MAN* was also significant (Table 57).

Table 57. Summary of univariate (*PC*) analysis based on Type III Sum of Squares (Dataset CT).

Main Effect	F-Score	Probability > F	Observed Power
FUN	53.5	0.000	1.00
MAN	4.3	0.005	0.87
Interaction Effect			
FUN* and *MAN	7.3	0.000	1.00

The univariate test of between-subjects effects for the dependent variable *RT* showed significance for the overall model at $\alpha = 0.05$ (F=31850.245, P>F=0.000). Main effects *FUN* and *MAN* were found to be significant. The interaction *FUN***MAN* was also significant (Table 58).

Table 58. Summary of univariate (*RT*) analysis based on Type III Sum of Squares (Dataset CT).

Main Effect	F-Score	Probability > F	Observed Power
FUN	123.4	0.000	1.00
MAN	66.8	0.000	1.00
Interaction Effect			
FUN* and *MAN	2.6	0.018	0.85

Analysis of Category Means

With regard to *PC*, category means for the variable *TEST*, or epoch were examined (Table 59). As expected, the child test group epoch 1 (92.63) recorded the lowest values of *PC*. Child test group epoch 2 (94.14) *PC* values increased notably from the first epoch. A significant increase was observed for child test group epoch 3 which yielded high accuracy (95.87). A noticeable decrease in *PC* was observed to fall below the third epoch for both child test group epoch 4 (94.71) and child test group epoch 5 (94.56). *PC* values again rose near the third epoch mean for child test group epoch 6 (95.20) (Figure 67).

Table 59. Means comparison of *PC* by *TEST* (epoch) (Dataset CT).

Epoch	**N**	δ_M	***PC* by *TEST***
E1	7003	0.53	92.63
E2	7117	0.40	94.14
E3	7248	0.33	95.87
E4	7160	0.49	94.71
E5	7149	0.42	94.56
E6	7197	0.35	95.20

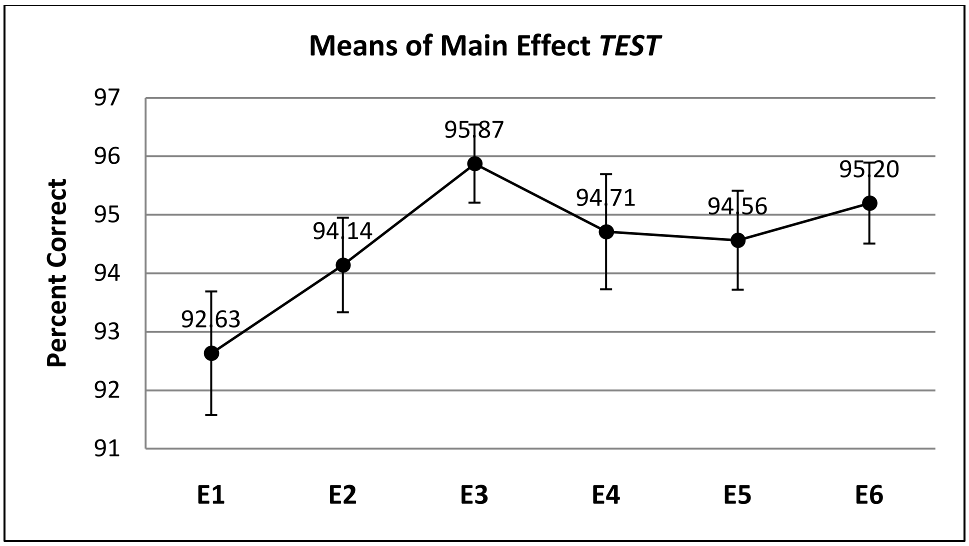


Figure 67. *PC* by *TEST* (epoch) (Dataset CT).

Mean reaction times (*RT*) for each category were also examined through time using the variable *TEST* (Table 60). As expected, the child test group epoch 1 (3501.52) recorded the highest values of *RT*. Each of the next four epochs recorded significantly lower *RT* values than the previous. Child test group epoch 2 (2956.41), child test group epoch 3 (2717.98), child test group epoch 4 (2565.06), and child test group epoch 5

(2240.97). Child test group epoch 6 (2245.95) recorded a very slight increase in *RT* from epoch 5 (Figure 68).

Table 60. Means comparison of *RT* by *TEST* (epoch) (Dataset CT).

Epoch	N	δ_M	***RT* by *TEST***
E1	7003	39.28	3501.52
E2	7117	31.52	2956.41
E3	7248	24.75	2717.98
E4	7160	23.88	2565.06
E5	7149	20.59	2240.97
E6	7197	18.98	2245.95

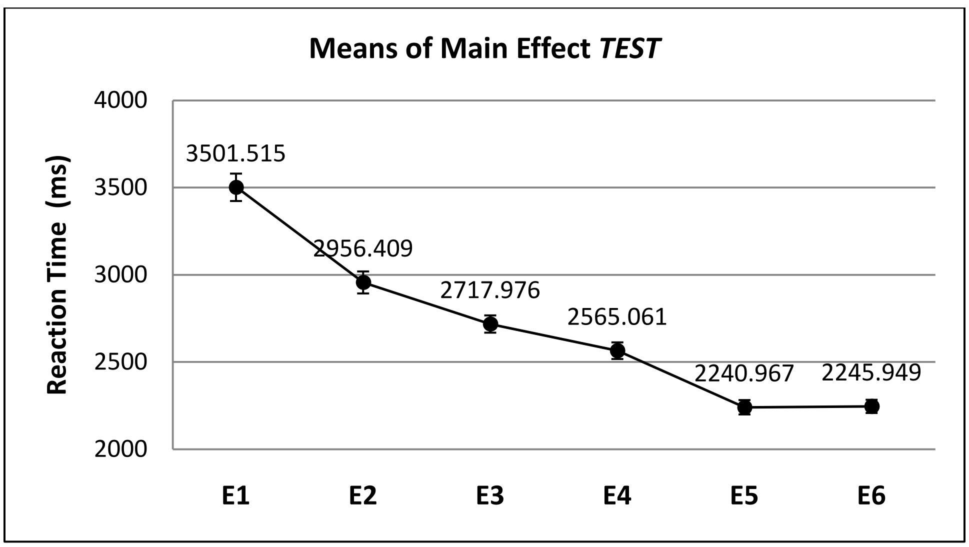


Figure 68. *RT* by *TEST* (epoch) (Dataset CT).

The means of *PC* for the variable *FUN* were examined by epoch (Table 61). The INTERSECT function was observed to produce *PC* values significantly lower than those of ERASE and UNION during nearly all epochs. Means of each function were observed to drop following the third epoch. Following the fourth epoch, the *PC* means of ERASE and UNION began to improve and approach their highest levels of the experiment by epoch 6. While the INTERSECT function demonstrated a significant increase in *PC* from the second to third epoch, it continued to record lower values of *PC* throughout the experiment following epoch 3 (Figure 69).

Table 61. Means comparison of *PC* by *FUN* (epoch) (Dataset CT).

Epoch	N	δ_M	***PC* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
E1	756	0.92	85.36	96.15	96.39
E2	756	0.70	88.53	97.10	96.79
E3	756	0.58	93.18	97.34	97.10
E4	756	0.85	92.58	95.75	95.79
E5	756	0.73	91.51	95.71	96.47
E6	756	0.60	91.03	96.94	97.62

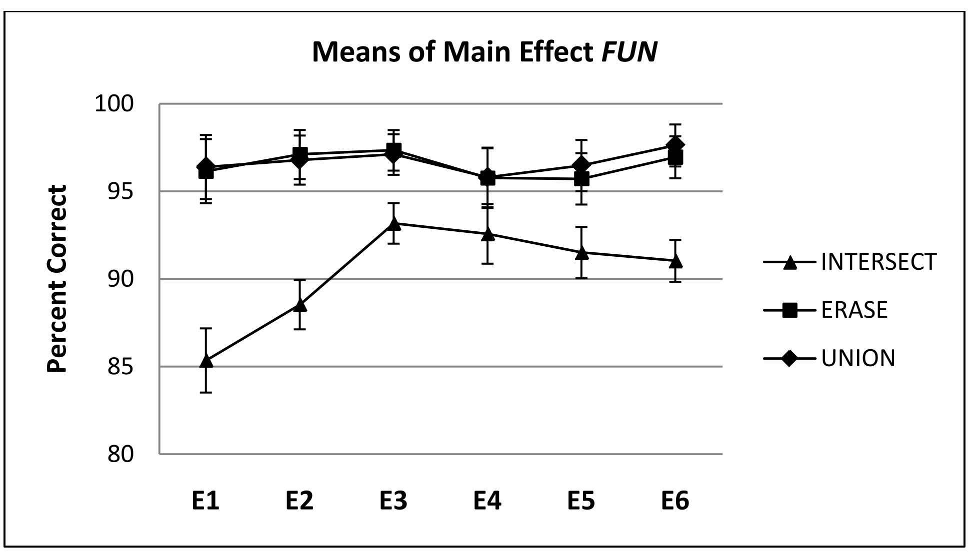


Figure 69. *PC* by *FUN* (epoch) (Dataset CT).

Mean reaction times (*RT*) for each epoch were also examined using the variable *FUN* (Table 62). The INTERSECT function recorded significantly higher *RT* values than ERASE and UNION during each epoch. *RT* values continued to improve through epoch 5 for all functions, and INTERSECT showed a continued drop during the sixth epoch. The INTERSECT function showed significant decreases in *RT* during each epoch through epoch 5. Significant lowering of *RT* means were observed for ERASE and UNION functions between epochs 1 and 2 as well as epochs 4 and 5 (Figure 70).

Table 62. Means comparison of *RT* by *FUN* (epoch) (Dataset CT).

Epoch	N	δ_M	***RT* by *FUN***		
			INTERSECT	**ERASE**	**UNION**
E1	756	68.03	4101.94	3304.07	3098.53
E2	756	54.60	3332.63	2855.16	2681.44
E3	756	42.87	3057.74	2515.60	2580.59
E4	756	41.35	2862.24	2378.79	2454.15
E5	756	35.66	2484.96	2112.31	2125.64
E6	756	32.87	2404.90	2154.42	2178.53

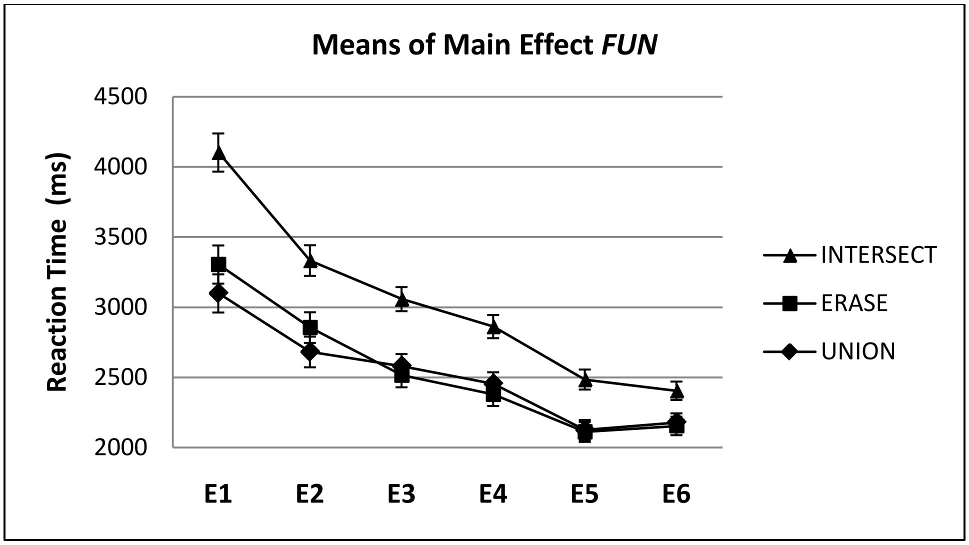


Figure 70. *RT* by *FUN* (epoch) (Dataset CT).

Student-Newman-Keuls range of group means for the variable *FUN* revealed significant differences for *PC* (Table 63) and *RT* (Table 64). Significant differences in *PC* were found between the INTERSECT (90.36) category with the lowest number of correct answers and both ERASE (96.50) and UNION (96.69) (Figure 71). With regard to *RT*, significant differences were found between the INTERSECT (3040.74) function and both the ERASE (2553.39) and UNION (2519.81) functions (Figure 72).

Table 63. Means comparison of *PC* by *FUN* based on S-N-K (Dataset CT).

FUN	**N**	δ_M	***PC* by epoch**	
			Subset	
			1	**2**
INTERSECT	252	0.49	90.36	
ERASE	252	0.49		96.5
UNION	252	0.49		96.69
Sig.			1	0.784

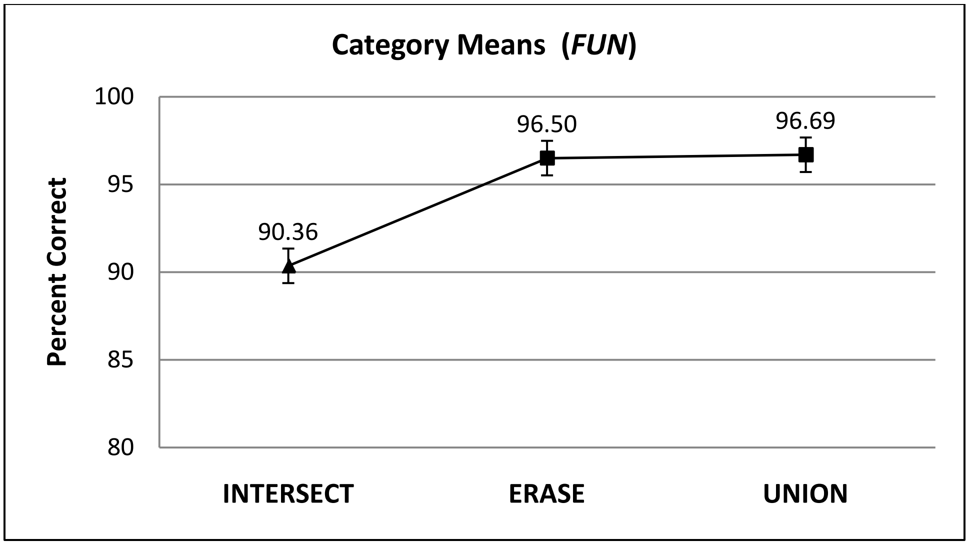


Figure 71. *PC* by *FUN* (Dataset CT). Dissimilar point symbols designate significantly different category means.

Table 64. Means comparison of *RT* by *FUN* based on S-N-K (Dataset CT).

FUN	**N**	δ_M	***RT* by epoch**	
			Subset	
			1	**2**
INTERSECT	252	26.25	3040.74	
ERASE	252	26.25		2553.39
UNION	252	26.25		2519.81
Sig.			0.366	1

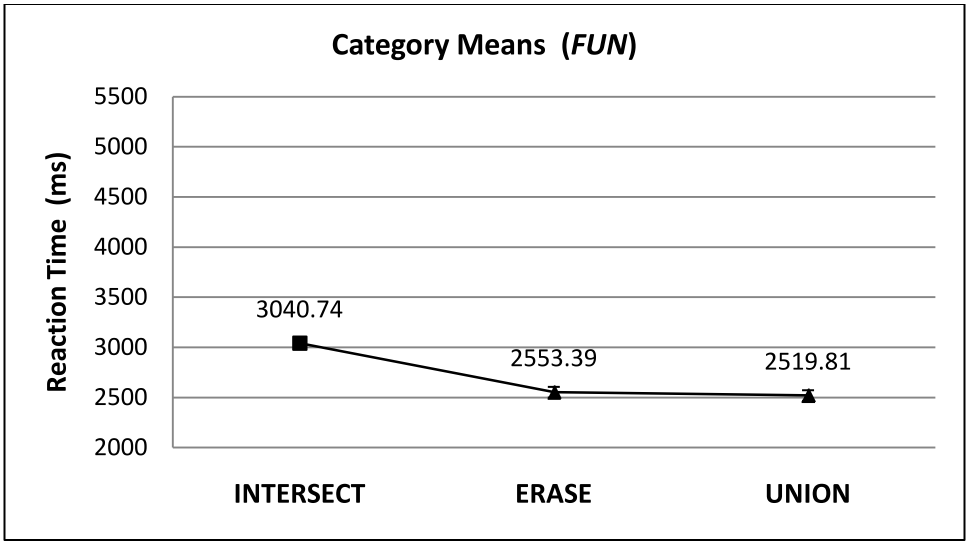


Figure 72. *RT* by *FUN* (Dataset CT). Dissimilar point symbols designate significantly different category means.

PC means for the variable *MAN* were examined by epoch (Table 65). Following the first epoch, a general trend of lower *PC* values for the input manipulations of A1 and A2 were observed throughout the experiment. Significance within manipulation was only confirmed between the second and third epochs for the A1 input. All manipulations followed the general trend of increase in performance through epoch 3 followed by a fourth epoch drop and recovery by epoch 6. Results of A2 show continued decrease in performance from epoch 3 through the sixth epoch (Figure 73).

Table 65. Means comparison of *PC* by *MAN* (epoch) (Dataset CT).

Epoch	N	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
E1	756	1.06	92.86	92.01	93.76	91.91
E2	756	0.81	91.48	93.33	96.19	95.56
E3	756	0.67	95.13	95.50	96.88	95.98
E4	756	0.98	94.18	93.55	95.34	95.77
E5	756	0.85	93.55	93.39	96.24	95.08
E6	756	0.69	95.19	92.49	97.04	96.09

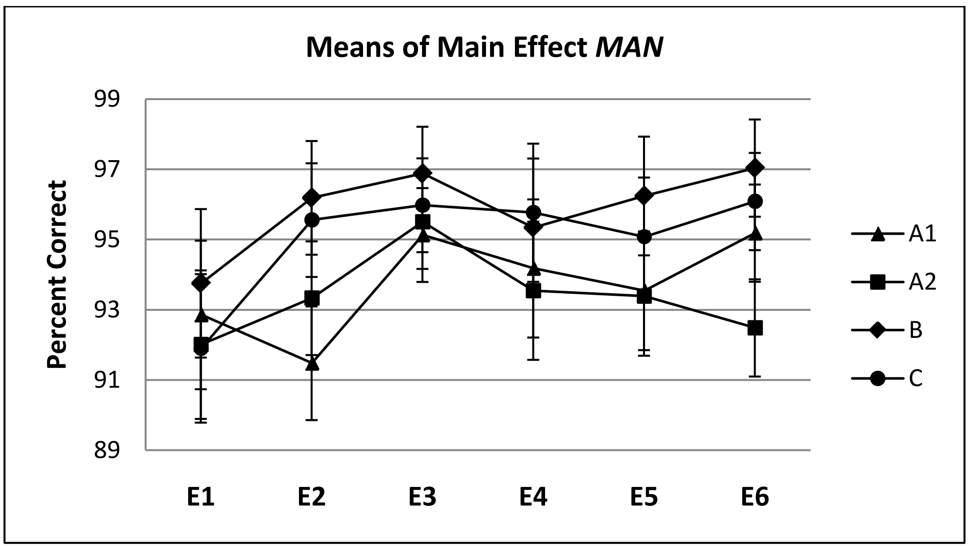


Figure 73. *PC* by *MAN* (epoch) (Dataset CT).

RT means of *MAN* by epoch were also examined (Table 66). Similar to the results for *FUN*, significant decreases in each *MAN* were observed between epochs 1 and 2 as well as epochs 4 and 5. Manipulation B also improved performance during the third epoch. The general trend was a decrease in *RT* mean through epoch 5, where means appeared to have leveled off by epoch 6 (Figure 74).

Table 66. Means comparison of *RT* by *MAN* (epoch) (Dataset CT).

Epoch	N	δ_M	***RT* by *MAN***			
			A1	**A2**	**B**	**C**
E1	756	78.56	3643.86	3711.39	3253.27	3397.54
E2	756	63.05	3126.79	3249.51	2653.11	2796.23
E3	756	49.50	2927.47	3015.73	2304.52	2624.19
E4	756	47.75	2745.58	2790.33	2248.62	2475.72
E5	756	41.17	2342.41	2470.76	1984.08	2166.62
E6	756	37.96	2365.65	2453.17	1965.61	2199.37

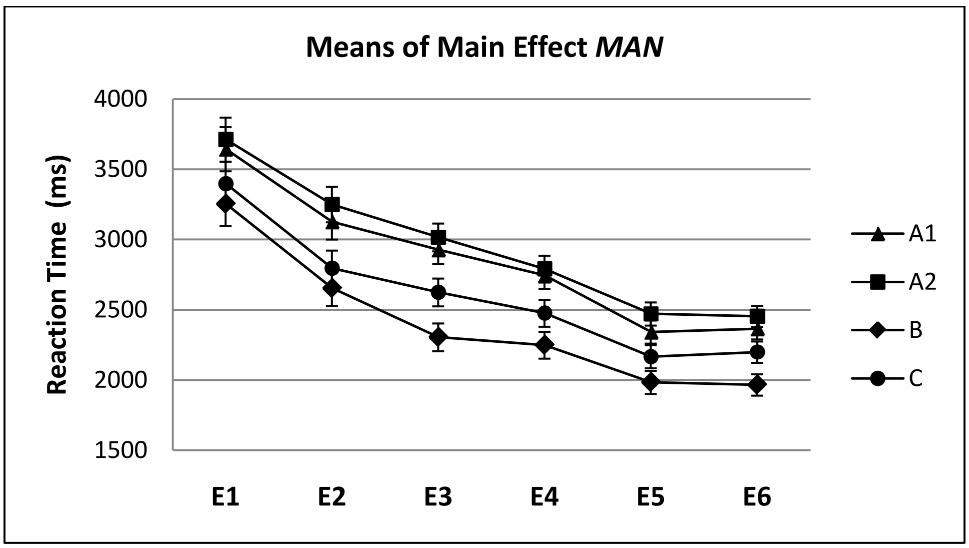


Figure 74. *RT* by *MAN* (epoch) (Dataset CT).

The *MAN* variable also revealed significant differences of category means for both *PC* (Table 67) and *RT* (Table 68) when analyzed using a Student-Newman-Keuls range of group means test. Significant differences in *PC* were found between the spatial manipulation B and both A1 and A2. The highest percent correct was recorded when solving for the function (95.91) manipulation while the first input (93.73) and second input (93.38) manipulations elicited lower accuracy (Figure 75). The output (95.06) manipulation was not significantly different than any other manipulation. Significant differences in *RT* were found between each of the manipulations A1, A2, B, and C. Subjects answered the function (2401.54) manipulation fastest, followed by the output (2609.94) manipulation, and then the first (2858.62) and second (2948.48) input manipulations (Figure 76).

Table 67. Means comparison of *PC* by *MAN* based on S-N-K (Dataset CT).

MAN	**N**	δ_M	***PC* by epoch**	
			Subset	
			1	**2**
A2	189	0.57	93.38	
A1	189	0.57	93.73	
C	189	0.57	95.06	95.06
B	189	0.57		95.91
Sig.			0.093	0.294

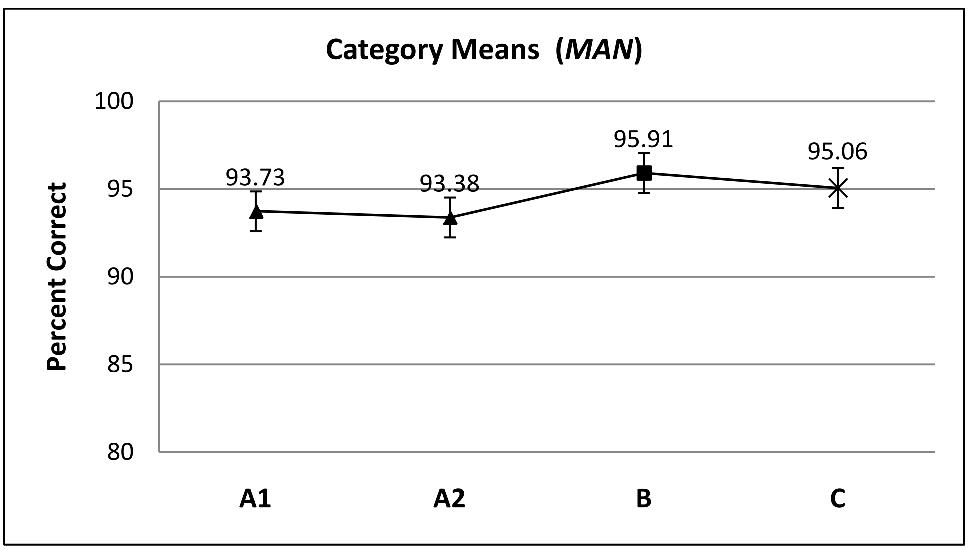


Figure 75. *PC* by *MAN* (Dataset CT). Dissimilar point symbols designate significantly different category means.

Table 68. Means comparison of *RT* by *MAN* based on S-N-K (Dataset CT).

MAN	N	δ_M	*RT* by epoch Subset 1	2	3	4
A2	189	30.31	2948.48			
A1	189	30.31		2858.62		
C	189	30.31			2609.94	
B	189	30.31				2401.54
Sig.			1	1	1	1

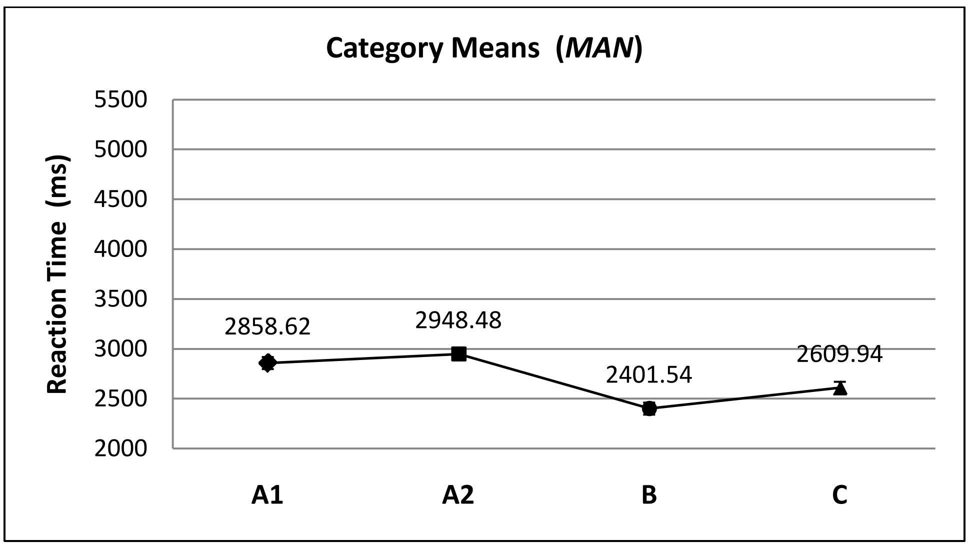


Figure 76. *RT* by *MAN* (Dataset CT). Dissimilar point symbols designate significantly different category means.

Discussion of Category Means

Although *PC* exhibited a significant increase from epoch 1 to epoch 6, each sequential test did not exhibit a *PC* increase. Epochs 1, 2, and 3 exhibited consecutive increases in *PC* with observed significance during epoch 3. A decrease in *PC* was observed for epochs 4 and 5. The *PC* for epoch 6 rose to the level achieved in epoch 3. This may show that students reached a point of diminishing return at the third epoch.

The decrease in *PC* of the fourth and fifth epochs with respect to the third and final epochs may help to illustrate this phenomenon by suggesting that the students were familiar with the map overlay concept to the point that they became bored with the tests and were careless with their answers. The overall trend for *RT* was to decrease through the series of epochs. Each of the first five epochs saw a significant decrease in *RT*. Subjects clearly became more confident in choosing answers with each subsequent test. The overall trend of increasing *PC* and decreasing *RT* indicates that the students became more efficient reading and answering the map overlay questions throughout the experiment. As suggested in many other studies, practice aides in spatial skill development (Casey, 1996; Lloyd & Bunch, 2005; Cherney, 2008). The performance increases exhibited by the child test group throughout the experiment support this statement.

Repeated measures analysis of Dataset CT revealed significance in the mean values of *PC* and *RT* among the six child test group epochs for *FUN* and for *MAN*. Throughout the experiment, subjects recorded significantly higher *PC* values for the ERASE and UNION functions than the INTERSECT function. The ERASE and UNION functions were also completed with lower reaction times than the INTERSECT function. The B manipulation was synonymous with significantly higher *PC* values than the A1 and A2 manipulations. The B manipulation was also synonymous with the lowest times of all spatial manipulations, and the A1 and A2 manipulations represented the highest times. The higher *PC* means and lower *RT* means indicated an increased awareness and recognition of the type of function used within each test question. When viewed in combination with the univariate analyses of Datasets E1 and E6, these results show that the trends for the apparent difficulty of the INTERSECT function and the recognition of the appropriate function were common throughout the experiment, and not isolated phenomena of the final epoch.

Analysis of Interaction Effects

Statistical significance was found for the two-way interaction between *FUN* and *MAN* with respect to *PC* (Table 57) and *RT* (Table 58). An interesting pattern was found with questions pertaining to the B manipulation. *PC* values were lower for this manipulation than those recorded for ERASE and UNION functions, but were higher for the INTERSECT function (Table 69, Figure 77). *RT* values were found to be nearly a second lower for the B manipulation with respect to the INTERSECT function (Table 70, Figure 78).

Table 69. Means comparison of *PC* by *FUN* and *MAN* (Dataset CT).

FUN	**N**	δ_M	***PC* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	252	0.99	86.76	86.81	94.80	93.10
ERASE	252	0.99	97.32	96.60	96.51	95.53
UNION	252	0.99	97.11	96.72	96.42	96.54

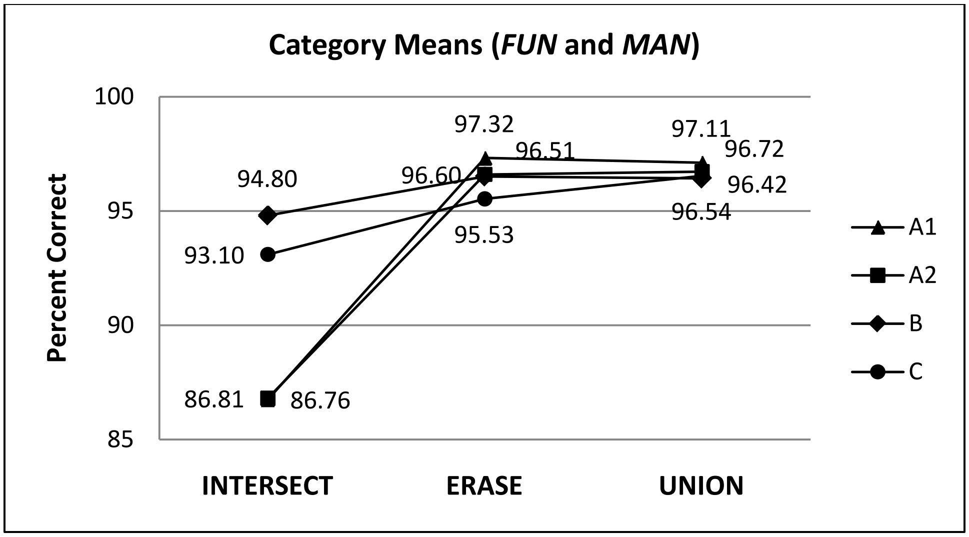


Figure 77. The two-way interaction effect on *PC* for *FUN* and *MAN* (Dataset CT).

Table 70. Means comparison of *RT* by *FUN* and *MAN* (Dataset CT).

FUN	**N**	δ_M	***RT* by *MAN***			
			A1	**A2**	**B**	**C**
INTERSECT	252	52.50	3196.63	3352.82	2760.50	2854.36
ERASE	252	52.50	2755.56	2821.30	2183.24	2456.46
UNION	252	52.50	2626.75	2673.44	2259.68	2520.00

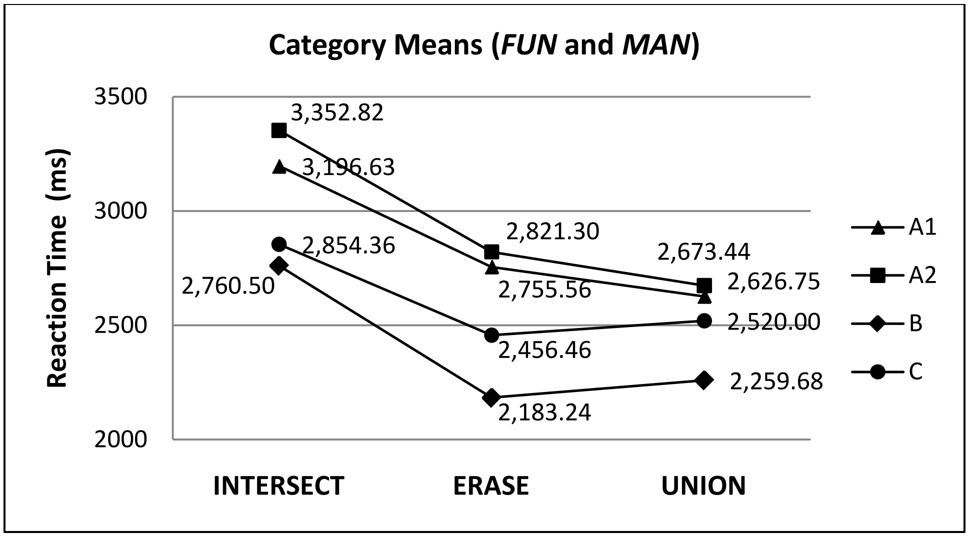


Figure 78. The two-way interaction effect on *RT* for *FUN* and *MAN* (Dataset CT).

Discussion of Interaction Effects

The child test group demonstrated trends similar to those exhibited by the other groups of *PC* and *RT* means within the two-way interaction between *FUN* and *MAN*. Once again, the manipulations of ERASE and UNION functions showed relatively little differences between the four spatial manipulations. The INTERSECT function provided the area for discovery of differences. The manipulations of B and C provided the two highest PC means associated with INTERSECT. *RT* means actually followed a recurrent trend within this analysis. *RT* means increased in order from B, to C, to A1, and finally A2 manipulations for each of the functions of INTERSECT, ERASE, and UNION. As with the epoch 1 analysis, the A1 and A2 manipulations for the INTERSECT function provided the highest *RT* values.

Situational Test of Ability

Twenty-two of the sixty-four child control group students answered the subjective question correctly, resulting in a 34 percent accuracy for the group. The child test group scored 68 percent accuracy with fourty-three of the sixty-three students choosing the correct answer. The average “difficulty” recorded by the control group was a 6 (slightly hard) versus a 4 (slightly easy) for the test group. As a whole, the test group recorded more correct answers and found the question to be easier than did the control group. These results coupled with the observed significant increases in percent correct and decreases in reaction time recorded throughout multiple epoch testing demonstrate that learning was achieved. Cherney (2008) suggested that if subjects perform a task significantly faster, more accurately, and with less perceived difficulty, then they have learned something that enhanced performance. Sweller (2004) states that performance refers to the end result of a task and serves as an indicator of the levels of mental load and mental effort exerted by an individual during a task. Paas and Van Merrienboer (1994) state that schemata are cognitive frameworks within long-term memory that enable problem-solvers to more efficiently perform tasks by enabling individuals to recognize problems and apply known solutions. Schema development signifies the presence of learning processes. These results indicate that the instruction and testing technique performed during this study was more effective than the traditional techniques experienced by the child control group at developing a spatial cognitive schema specific to map overlay in young adolescents. Therefore, it can be concluded that the procedures laid out in this study have proven to facilitate learning specific to the map overlay concept in young adolescents.

CHAPTER V

CONCLUSIONS

The purpose of this study was to demonstrate the effectiveness of InGIScience research by developing an instructional technique based upon knowledge compiled through its unique interdisciplinary approach and application specific to young adolescents and the complex spatial processes of the map overlay concept. There has been supporting evidence that individuals aged 12 to 14 years have the cognitive ability to perform complex spatial tasks (Flavell et al., 1986). Previous studies have underscored the belief that young adolescents do not have sufficient incidental knowledge of such processes to perform at a mature level (Bunch, 2000; Lloyd & Bunch, 2003; Battersby et al., 2006). Underlying the goal of this study was the assumption that instructional techniques developed through an Instructional Geographic Information Science perspective would provide the means for young adolescents to learn complex spatial concepts such as map overlay.

The first hypothesis stated that map overlay schema development could be obtained in young adolescents through repetitive instruction and testing. The results of the analysis supported this statement. The acknowledgement of schema development was based on the idea that schemata are frameworks of knowledge held in long-term memory that aid in the efficient storage and retrieval of information resulting in what is generally regarded as learned information or knowledge. The child test group significantly out-performed the child control group by the end of the experiment with respect to *PC*. The increase in *PC* for the child test group was 50 percent greater than that of the child control group from initial to final testing. This group also produced a significantly higher *PC* than the adult group by the end of the study. The undergraduate students of the adult group represented individuals having a mature cognitive level regarded as expert. The child test group also achieved a significantly lower *RT* than the other groups by the end of the experiment. This lowering of *RT* is important when considering two other observations; the child test group had an initial *RT* significantly higher than the child control group, and the child control group showed a significant decrease in *RT* during the final test. The unparalleled improvements in *PC* and *RT* throughout the experiment by the child test group indicate that map overlay schema development occurred. The performance of the child control group was also significant in many respects compared to the adult group. It was also very interesting to observe that during the sixth and final epoch, the child control group out-performed the adult group with respect to *RT* and was at the same level of *PC*. These young adolescents experienced only two iterations of the test, yet they recorded results in line with the supposed cognitively mature adults.

These results do not follow the findings observed in other recent studies involving young adolescents. Research by Bunch (2000), Lloyd and Bunch (2003), and Battersby and others (2006) all reveal that young adolescents typically perform at lower levels than adults on tasks of spatial abilities. What is important to note about these particular previous studies is the fact that they were not designed to test for the ability of young adolescents to learn the specific tasks through practice or any other method. They were concerned with identifying whether differences existed between the spatial abilities of their respective subject groups. In each, similar cognitive abilities between groups were assumed and later rejected by analysis indicating differences in abilities by age. This study separates itself from previous map overlay and map-reading task oriented studies by specifically instructing and testing young adolescents in an effort to determine if and to what extent learning could occur.

Many recent studies have demonstrated that activities such as training (Terlecki & Newcombe, 2005) and practice (Cherney, 2008) aid in the acquisition of spatial skills. Prior test-taking experience has also proven to act as a surrogate to practice and enhance spatial skills (Terlecki & Newcombe, 2005). While incorporating the instructional technique of repeated practice and test-taking exercises, the design of this study also borrowed from Van Merrienboer and other's (2003) formula for repetition of part-task lessons. However, this study of the spatial processes of the map overlay concept separates itself from these previous studies by specifically subjecting young adolescents to repeated instruction and testing and then comparing their performance to that of adults. Terlecki and Newcombe (2005) and Cherney (2008) tested undergraduate students for performance gains through time and differences between the biological sexes respectively. Evidence of this study's success exists in the high performance values of *PC* and *RT* as well as the high performance and low perceived effort of the child test group during the situational test. Repeated instruction and practice in the form of test-taking activities appears to have provided the environment and conditions for enhanced performance by the young adolescents.

It was hypothesized that young adolescents would exhibit no differences in performance due to specific types of map overlay function. Battersby and others (2006) tested young adolescents on their ability to properly utilize specific map overlay functions. It was reported that no difference between map overlay operators was observed. Consistent within all groups throughout the current study was the observation that significant differences existed for *PC* and *RT* between the map overlay functions of INTERSECT and both ERASE and UNION. Subjects within all three groups recorded lower values of *PC* and higher values of *RT* for questions involving the INTERSECT function. This phenomenon was not altogether unexpected as Albert and Golledge (1999) observed a similar trend in their study of undergraduates. Their logical operator 'AND' served as a surrogate to the intersect function and was observed to produce significantly lower performance values than surrogates for the functions of erase and union. Therefore, the results of this study do not support the null hypothesis that no difference in performance would exist due to specific types of map overlay function. As opposed to map overlay erase and union functions, the intersect function often results in an object that is void of many of the recognizable outer edges represented in the parent objects. This lack of familiar outer edges to compare against parent or other input elements of map overlay operations making it more difficult to quickly and accurately recognize the specific physical elements within these types of operations.

It was also hypothesized that young adolescents would exhibit no differences in performance due to spatial manipulations of map overlay operations. Consistent within all groups throughout the study was the observation that significant differences existed for *PC* and *RT* between the spatial manipulations of missing elements. The act of solving for the elements of either the first or second input consistently resulted in lower values of *PC* and higher values of *RT* throughout the experiment. The spatial manipulation specific to the function type was observed to produce values of *PC* and *RT* even with or significantly superior to the values of all other manipulations throughout the experiment. Thus, questions requiring subjects to solve for either of the input manipulations proved to be significantly more challenging for all groups, and those requiring the indication of the correct map overlay function were the least challenging. These results do not support the null hypothesis that no difference in performance would exist due to manipulation type.

Observations of lower values of *PC* and higher values of *RT* for the input manipulations indicate that this type of question proved most difficult for subjects. A missing input element of a map overlay formula requires the subject to mentally complete the map overlay operation in a manner reversed to typical encounters. Map overlay operations are typically encountered by the need to perform a specific function upon two or more existing objects, thus providing all the foundational pieces of the map overlay puzzle to be solved. Missing input elements require the subject to consider all potential inputs against the conditions specified by the complete operation that would result in the given output. The additional mental reasoning required by these types of operations equate to longer reaction times and an increased probability of choosing an incorrect solution. The observation of higher performance values associated with solving for the function manipulation makes sense. These questions inherently contain all representative objects participating in the operation. The subject is simply required to recognize the function performed on the given input elements with respect to the given output element. Each output element typically has some easily recognizable features that set it apart from output features of other function operations. For example, output elements of an erase function typically result in an output that contains an apparent missing piece or whole within its outer edge. Union functions typically result in combinations of input elements that are filled and have outer edges easily discernable as common to the input elements. Outputs of intersect functions are typically much smaller than any perceived combination of the input elements. For these reasons, it becomes clear that once given a map overlay formula containing both inputs and an output, only a quick glance and categorization of the output element with respect to the input elements is needed before determining the appropriate function element.

Drawing upon the results of similar recent studies, it was hypothesized that there would be no performance differences between young adolescent males and females in the map overlay concept. Albert and Golledge (1999), Bunch (2000), Lloyd and Bunch (2003), and Battersby and others (2006) all reported no significant differences between the performances of males and females with regard to map overlay and other similar map-reading tasks. Other previous studies are divided on the subject of sex-based differences in spatial abilities. Among many other studies (Liben & Golbeck, 1980; Law et al., 1993; Halpern, 2000), the findings of Linn and Petersen (1985) suggest that males tend to perform better on spatial tasks than females. Other research points to specific spatial tasks that have shown a consistent female advantage in performance when compared to males (James & Kimura, 1997; Choi & Silverman, 2003). The results of this study do not reveal any significant differences between the sexes with regard to the overall models. *SEX* was a component of several significant two-way interactions; however these results were mixed. For example, initial epoch test results indicated that males within the child test group recorded higher values of *PC* than females, while the females achieved the highest *PC* values within the child control group. Males produced the lowest *RT* values as a whole during the initial epoch. Males also significantly out-performed females with respect to the INTERSECT function. Child test group females recorded *RT* and *PC* values superior to males during the second epoch; however, significance was not observed for values of *RT*. No differences were observed during this final epoch with respect to specific map overlay function. These mixed two-way interaction results coupled with a lack of significance of *SEX* for the overall model lends support for the null hypothesis that no differences exist between males and females with regard to the ability to learn the map overlay concept.

Studies spanning three decades show practice as a means of nullifying any differences between males and females (Connor et al., 1978; Cherney, 2008). Within this study, it was observed that females closed the *PC* and *RT* gaps with males recorded during the initial epoch. They also increased performance with respect to the INTERSECT function by the final epoch. Practice may have played an important role in closing these initially observed gaps between males and females within this study.

Another explanation for the apparent lack of differences between spatial abilities of the sexes may be explained by studies suggesting that identifiable gender roles or levels of masculinity and femininity are better suited to explain what was once seen as a purely biological individual difference. Lloyd and Bunch (2008) utilized the Bem Sex Role Inventory (BSRI) (Bem, 1974) in a study of the ability of males and females to identify the locations of states within the United States. They concluded that specific correlations existed between gender and task performance that were not readily observable through biological sex variation alone.

The hypothesis that performance of the young adolescents within the test group would increase until reaching a level equivalent to experts was also supported. The child test group subjects far exceeded the performance of the adult group by the final epoch of instruction and testing. The highest observed value of *PC* was recorded during the third epoch. This round of testing was subsequently followed by fourth and fifth epoch *PC* scores lower than that of the third epoch. Epoch 6 scores had again climbed to the same level of significance as Epoch 3, signifying that a point of diminishing return had been reached during the third epoch. With respect to *RT*, each epoch resulted in times significantly lower than in previous epochs. Child test group subjects had significantly separated their times from the adults by the second epoch. A point of diminishing return of *RT* was not observed throughout the six epochs. It is also important to note the increased performance of the child control group from the initial to final epoch. Initial values of *PC* and *RT* were significantly different from the adult group; however, final epoch *PC* scores were in line with the results of the adult group, and *RT* values were significantly lower than those of the adult group. The adult group received initial epoch instruction and testing. The child control group received initial epoch instruction and testing as well as final epoch testing. Perhaps the mere act of taking the final epoch test served as added practice adequate to enhance performance. These results follow in line with those of Terlecki and Newcombe's (2005) observations that subjects engaged in repeated practice consistently recorded increases in performance without reaching a point of leveling off.

Observations of very high accuracy scores of map overlay by students in a study conducted by Battersby and others (2006) indicate that once learned, this spatial ability results in highly repeatable results. The very low *RT* values and very high *PC* values recorded by the young adolescents within the current study in relation to the lower scores recorded during the study by Battersby and other (2006) point to the possibility of the presence of external conditions that allowed for the current success. The young adolescents participating in the current study all attended a private catholic middle school. Average student to teacher ratio in private schools is often below that of public schools and in this case was around 20 to 1. It could be possible that the socioeconomic status of participants may have also been a contributing factor to an overall high performance by participants; however, no apparent lean towards one extreme was observed, and inquiry reported that scholarships based upon factors including financial need are awarded by the institution. It could be possible that one, or both, or none of these conditions contributed to the results of this study. What is certain is the young adolescents who participated in this study achieved significantly improved performance throughout the course of the experiment. Experience with repeated testing appears to have equated to improved performance to the level that learning was achieved.

Bunch (2000) and Cherney (2008) called for additional research identifying training and practice techniques that enhance spatial abilities. Bunch (2000) specifically suggested that additional research be conducted on the testing of fundamental map tasks such as map overlay. Cherney (2008) stated that spatial skills and abilities were related to one another in that spatial skills were learned activities that contributed to the acquisition of spatial abilities. Skills are additive, and when learned, combine with pre-existing skills to help people perform spatial tasks more efficiently. She also stated that measurements of spatial task performance that demonstrate increased accuracy, faster reaction times, and lowered perceived difficulty all point to the presence of learning. This study has shown that the practice of repetitive instruction and testing has proven effective for enhancing spatial abilities with regard to the map overlay concept. This study found that with practice, young adolescents can learn the map overlay concept and perform at levels equal to or greater than adults. This study has helped to answer the question of whether this development of spatial abilities is possible.

Future Research

Given the results of the experimental testing through epochs and the situational awareness test, some important questions regarding instructional methodology and the cognitive abilities of young adolescents are answered. Observations of lower *Reaction Times*, higher *Percent Correct* scores, and lower mental effort by the child test group indicate that this instructional technique is may be more effective than the traditional techniques used in the classroom for the child control group. Future studies could specifically test for the instructional efficiency of this method by collecting subjective mental effort ratings throughout epoch testing. The collection would enable efficiency z-scores along the lines of those collected in similar studies of spatial abilities (Lloyd & Bunch, 2008; 2010). It would also be interesting to determine how the child control and child test groups would compare with the adult group given a sixth epoch test and a situational awareness test for the adult group. Would adults demonstrate a similar increase in performance similar to the child control group given an additional test iteration? Would the young adolescents of the child control group out-perform the adults on a situational awareness test? Venn diagrams are very similar to the map overlay concept and are typically used as instructional aides in elementary school classrooms. Future studies of elementary school aged children utilizing repeated practice techniques may provide insight into the ability of these young students to also learn the map overlay concept. Future studies might also consider utilizing this instructional technique to specifically test young adolescents or younger children for schema development of additional spatial abilities such as mental rotation tasks. Previous studies (Voyer et al., 1995; Halpern, 2000) have shown that males tend to perform better than females on tasks of mental rotation. Could a study of young adolescents following the procedures of the current study reveal a similar closing of performance gaps between males and females? The incorporation of additional individual difference variables such as gender identity and 2D/4D ratios could also serve to add to the current body of research.

This technique was conceptualized as a means to teach spatial concepts to young adolescents and reduce the barriers of GIS implementation into the classroom. While it has accomplished these two tasks, the effectiveness relative to full GIS implementation into the classroom is still not known. Would GIS hardware and software financial investments coupled with temporal investments of teaching students to learn specific GIS applications prove more effective and/or efficient? Perhaps the 2010 passing of the Teaching Geography is Fundamental Act (H.R. 1240) and the potential ESEA reauthorization will allow for the funding of additional research into the use of instructor-led GIS lessons in classrooms.

Broader Implications

This study shows that schema development of complex spatial concepts such as map overlay can be aided by the incorporation of instructional techniques supported through the research of Instructional Geographic Information Science (InGIScience) into the learning process. Through the agglomeration of techniques proven through empirical research across three highly respected academic disciplines, InGIScience directly seeks to explain and target ways of improving spatial abilities of today's youth.

Of interest to this study was the removal of first-hand interaction with the GIS by the students. Removed from the learning experience are any distractions caused by the need for students or instructors to learn specific software applications. The need for numerous hardware installations and software licenses is also removed from instruction. In so doing, a great deal of extraneous load was able to be released and potentially utilized as germane load. Practice in the form of repeated instruction and testing resulting in extraordinary gains in performance within just three iterations. Once the foundational schema are developed, then more robust studies may begin to take place, possibly incorporating GIS as a more hands-on instructional aide.

GIS is functionally a dynamic tool for the study of spatial relationships between and among people, places, and objects throughout the world. This dynamic quality lends itself to the types of inquiry-based learning that is at the forefront of constructivist theory education today. The creation, production, and analysis of interactive maps enable students to hone the spatial analytical skills that are at the core of this study. In so doing, the discipline of geography will benefit from the achievement of its educational standards and the acknowledged importance it plays in aiding critical thinking abilities in students.

Our educational system has remained slow in its incorporation of geographic principles into the curriculum of schools. Those who incorporate within their knowledge base the principle spatial thinking dimensions of spatial visualization, spatial orientation, and spatial relations will have a greater advantage in their ability to reason in world connections. InGIScience is proving that the incorporation of these concepts and the development of these spatial abilities are possible. It is paramount that thinking form a geographic point of view is incorporated in the classrooms of our youth if our nation is to continue to lead within an ever-increasingly global society.

Our world is becoming an ever-increasingly smaller place to live. The advent of the Computer Age and the Internet is allowing for the almost direct contact between cultures never before having been introduced to each other, let alone engaged in daily interaction. This phenomenon has necessitated the advancement of geographic thought in our society. This advancement must primarily take place in the education of our youth. If it can be shown a formal structure exists to the use of GIS for effective education of geographic thought processes, then the national geography standards have a better chance of being met by students. The successful citizens of tomorrow's world society will be those with the greatest understanding of the spatial interconnectedness of the world's regions and its peoples. The accomplishment of the intellectual goals set forth by the standards will undoubtedly ensure the success of today's students as tomorrow's world leaders.

REFERENCES

Albert, W.S., & Golledge, R.G. (1999). The use of spatial cognitive abilities in geographical information systems: The map overlay operation. *Transactions in GIS, 3*(1), 7-21.

Annett, M. (1985). *Left, right, hand and brain: The right shift theory* London, England: Erlbaum.

Annett, M. (2002). *Handedness and brain asymmetry: The right shift theory* Hove, UK: Psychology Press.

Audet, R., & Abegg, G. (1996). Geographic information systems: Implications for problem solving. *Journal of Research in Science Teaching, 33*, 21-45.

Baddeley, A. (1986). *Working Memory* Oxford, U.K.: Clarendon Press.

Baddeley, A. (1998). *Human Memory* Boston, MA: Allyn and Bacon.

Battersby, S.E., Golledge, R.G., & Marsh, M.J. (2006). Incidental learning of geospatial concepts across grade levels: Map overlay. *Journal of Geography, 105*, 139-146.

Bednarz, R.S. (2002). The quality and quantity of geography education in the United States: The last 20 years. *International Research in Geographical and Environmental Education, 11*(2), 160-170.

Bednarz, S.W. (2004). Geographic information systems: A tool to support geography and environmental education? *GeoJournal, 60*, 191-199.

Bednarz, S.W., Bettis, N.C., Boehm, R.G., deSouza, A.R., Downs, R.M., Marran, J.F., Morrill, R.W., & Salter, C.L. (1994). *Geography For Life: National Geography Standards 1994* Washington, D.C.: National Geographic Research & Exploration.

Bednarz, S.W., & Ludwig, G. (1997). Ten things higher education needs to know about GIS in primary and secondary education. *Transactions in GIS*, *2*(2), 123-133.

Bell, S., & Saucier, D. (2004). Relationship among environmental pointing accuracy, mental rotation, sex, and hormones. *Environment and Behavior, 36*, 251-265.

Bem, S. (1975). Measurement of psychological androgyny. *Journal of Consulting and Clinical Psychology, 42, 155*-162.

Blades, M., & Spencer, C. (1986). The implications of psychological theory and thodology for cognitive cartography. *Cartographica, 24,* 64-75.

Blazhenkova, O., & Kozhevnikov, M. (2009). The new object-spatial-verbal cognitive style model: Theory and measurement. *Applied Cognitive Psychology, 23*(5), 638-663.

Brosnan, M. (2006). Digit ratio and faculty membership: Implications for the relationship between prenatal testosterone and academia. *The British Journal of Psychology, 97,* 455-466.

Brown, M., & Broadway, M. (1981). The cognitive maps of adolescents: Confusion about inter-town distances. *The Professional Geographer, 33,* 315-325.

Brunken, R., Plass, J.L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, *38*(1), 53-61.

Bryce, J. (1902). The importance of Geography in education. *The Geographical Journal*, *19*(3), 301-313.

Bunch, R.L. (1999). Searching for color boundaries on maps. *Southeastern Geographer, 39*(2), 220-234.

Bunch, R.L. (2000). GIS and the acquisition of spatial information: Differences among adults and young adolescents. *Research in Geographic Education, 2*(2), 67-97.

Bunch, R.L., & Lloyd, R. (2000). The search for boundaries on choropleth maps: Color processing and map pattern effects. *Cartography and Geographic Information Science, 27*, 15-29.

Bunch, R. L., and Lloyd, R. (2006). The cognitive load of geographic information. *The Professional Geographer, 58*, 209-220.

Bunch, R., Nelson, E., Lloyd, R., Kane, M., & Tricot, T. (2008). Instructional Geographic Information Science: A Multidisciplinary Framework for Geospatial Technologies in Education. In A. Milson & M. Alibrandi (Eds.), *Digital Geography: Geo-spatial Technologies in the Social Studies Classroom* (pp. 227-245). Greenwich, CT: Information Age Publishing.

Casey, M.B. (1996). Understanding individual differences in spatial ability within females: A nature/nurture interactionist framework. *Developmental Review, 16,* 241-260.

Cherney, I.D. (2008). Mom, let me play more computer games: They improve my mental rotation skills. *Sex Roles, 59*, 776-786.

Cherney, I.D., & Collaer, M. (2005). Sex differences in line judgment: Relation to mathematics preparation and strategy use. *Perceptual and Motor Skills, 100*, 615-627.

Cherney, I.D., & Neff, N.L. (2004). Role of strategies and prior exposure in mental rotation. *Perceptual and Motor Skills, 98*, 1269-1282.

Cherney, I.D., Rendell, J., & McDonough, R. (2006). *The lines are drawn, but sex differences in spatial perception persist.* Poster presented at the Association for Psychological Science Annual Convention, New York, NY, May.

Choi, J., & Silverman, I. (2003). Processes underlying sex differences in route-learning strategies in children and adolescents. *Personality and Individual Differences, 34,* 1153-1166.

Connor, J.M., Shackman, M., & Serbin, L. (1978). Sex-related differences in response to practice on a visual-spatial test and generalized to a related test. *Child Development*, *49*, 24-29.

Cooke, R. (2002). Annual General Meeting. *Geographical Journal*, *168*, 264-271. doi: 10.1111/1475-4959.00054

Cowan, N., & Morey, C. (2006). Visual working memory depends on attentional filtering. *Trends in Cognitive Sciences, 10*, 139-141.

Daley, R. (2003). No Geographer Left Behind: A policy guide to geography education and the No Child Left Behind Act of 2001. Retrieved October 10, 2010, from http://www.nationalgeographic.com/foundation/pdf/NCLB-Geo-EducatorGuide.pdf

Downs, R.M., & Liben, L.S. (1991). The development of expertise in geography: Approach to geographic education. *Annals of the Association of American Geographers, 81*(2), 304-327.

Downs, R.M., & Stea, D. (1973). *Image and Environment* Chicago, IL: Aldine.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23,* 5-12.

Ediger, M. (2001). Assessment, geography, and the student. *Journal of Instructional Psychology, 28*(3), 150-154.

Falter, C., Arroyo, M., & Davis, G. (2006). Testosterone: Activation or organization of spatial cognition? *Biological Psychology, 73,* 132-140.

Feeney, A.E. (2003). Using interactive multimedia for dyslexic students in geographic education. *Journal of Geography, 102,* 21-28.

Fischer, M. (2001). Probing spatial working memory with the Corsi Blocks Task. *Cognition*, *45*, 143-154.

Flavell, J., Green, F., & Flavell, E. (1986). Development of knowledge about the appearance-reality distinction. *Monographs of the Society for Research in Child Development*, *51*(1, Serial 212).

Galea, L., & Kimura, D. (1993). Sex differences in route learning. *Personality and Individual Differences, 14,* 53-65.

Gallagher, S. (2010). *AAG Blueprint for Geography Education: Views on The Reauthorization of the ESEA in 2010 by the Association of American Geographers (AAG)*. Retrieved October 1, 2010, from http://www.aag.org/galleries/education-policy/blueprint_policy_statement.pdf

Gerjets, P., & Scheiter, K. (2003). Goal configurations and processing strategies as moderators between instructional design and cognitive load: Evidence from hypertext-based instruction. *Educational Psychologist, 38*(1), 33-41.

Gewin, V. (2004). Mapping opportunities. *Nature, 427*, 376–377.

Gilmartin, P.P. (1981). The interface of cognitive and psychophysical research in cartography. *Cartographica*, *18,* 9-20.

Gilmartin, P., and Patton, J. (1984). Comparing the sexes on spatial abilities: Map-use skills. *Annals of the Association of American Geographers, 74,* 605-619.

Golledge, R.G., Loomis, J.M., Klatzky, R.L., Flury, A., & Yang, X.L. (1991). Designing a personal guidance system to aid navigation without sight: Progress on the GIS component. *International Journal of Geographical Information Systems, 5,* 373-396.

Golledge, R.G., & Stimson, R.J. (1997). *Spatial Behavior: A Geographic Perspective* New York, NY: Guilford Press.

Goodchild, M.F. (1991). Towards a science of geographic information. In J. Cadoux-Hudson & I. Heywood (Eds.), *Geographic Information 1991: The Yearbook of the Association for Geographic Information* (Vol. 151, pp. 212-218). London, England: Taylor and Francis.

Goodchild, M.F. (1992). Geographical information science. *International Journal of Geographical Information Systems, 6*(1), 31-45.

Goodchild, M.F. (1993). Ten years ahead: Dobson's automated geography in 1993. *Professional Geographer, 45*(4), 444-446.

Gouchie, C., & Kimura, D. (1991). The relationship between testosterone levels and cognitive ability patterns. *Psychoneuroendocrinology, 16*, 323-334.

Halpern, D. (1992). *Sex differences in cognitive abilities* Hillsdale, NJ: Erlbaum.

Halpern, D. (2000). *Sex differences in cognitive abilities* (3rd ed). Mahwah, NJ: Erlbaum.

Halpern, D., & Crothers, M. (1997). The sex of cognition. In I. Ellis (Ed.), *Sexual orientation: Toward biological understanding* (pp 181-197). Westport, CT: Praeger.

Harris, L. (1981). Sex variation in spatial skill. In L. Liben, A. Patterson, & N. Newcombe (Eds.), *Spatial representations and behavior across the life-span* (pp. 83-125). New York, NY: Academic Press.

Jacobs, H. (1989). *Interdisciplinary Curriculum: Design and Implementation* Alexandria, VA: Association for Supervision and Curriculum Development.

James, T., & Kimura, D. (1997). Sex differences in remembering the locations of objects in an array: Location-shifts versus location-exchanges. *Evolution and Human Behavior, 18*, 155-163.

Jamison, W., & Signorella, M. (1987). Relations of masculinity and femininity in self-concept to spatial performance in adolescents. *The Journal of Genetic Psychology, 148*, 249-251.

Johnston, R.J., & Sidaway, J.D. (2004). *Geography and Geographers: Anglo-American Human Geography since 1945* (6th ed). New York, NY: Oxford University Press, Inc.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

Kane, M.J., Hambrick, D.Z., Tuholski, S.W., Wilhelm, O., Payne, T.W., & Engle, R.W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*, 189-217.

Kerski, J.J. (2001). A national assessment of GIS in American high schools. *International Research in Geographical and Environmental Education, 10*(1), 72-84.

Kerski, J.J. (2003). The implementation and effectiveness of geographic information systems technology and methods in secondary education. *Journal of Geography, 102*, 128-137.

Kitchin, R.M. (1996). Increasing the integrity of cognitive mapping research: Appraising conceptual schemata of environment-behaviour interaction. *Progress in Human Geography*, *20*(1), 56-84.

Kitchin, R.M. (1994). Spatial familiarity as a variable in cognitive mapping. *Swansea Geographer*, *31*, 42-52.

Kitchin, R.M., Blades, M., & Golledge, R.G. (1997). Relations between psychology and geography. *Environment and Behavior*, *29*(4), 554-573.

Kopec, R.J. (1984). *Geography: No 'where' in North Carolina 1984*. ERIC Document ED256630.

Kosslyn, S.M., Thompson, W.L., Gitelman, D.R., & Alpert, N.M. (1998). Neural systems that encode categorical versus coordinate spatial relations: PET investigations. *Psychobiology, 26*(4), 333-347.

Law, D.J., Pellegrino, J.W., & Hunt, E.B. (1993). Comparing the tortoise and the hare: Gender differences and experience in dynamic spatial reasoning tasks. *Psychological Science, 4*, 35-40.

Liben, L.S., & Golbeck, S.L. (1980). Sex differences in performance on Piagetian spatial tasks: difference in competence or performance? *Child Development, 51*, 594-597.

Ligocki, C. (1982). High school geography and the need for communication. *Journal of Geography, 81*, 188-190.

Linn, M., & Petersen, M. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development, 56*, 1479-1498.

Lloyd, R., & Bunch, R. (2003). Technology and map learning: Users, methods, and symbols. *Annals of the Association of American Geographers, 93,* 828-850.

Lloyd, R., & Bunch, R. (2005). Individual differences in map reading spatial abilities using perceptual and memory processes. *Cartography and Geographic Information Science, 32*, 33-46.

Lloyd, R., & Bunch, R. (2008). Explaining map-reading performance efficiency: Gender, Memory, and geographic information. *Cartography and Geographic Information Science, 35*(3), 171-202.

Lloyd, R., & Bunch, R. (2010). Learning geographic information from a map and text: Learning environment and individual differences. *Cartographica, 45*, 169-184.

Lo, C.P., Affolter, J.M., & Reeves, T.C. (2002). Building environmental literacy through participation in GIS and multimedia assisted field research. *Journal of Geography, 101*, 10-19.

Loehlin, J., McFadden, D., Medland, S., & Martin, N. (2006). Population differences in finger-length ratios: Ethnicity or latitude? *Archives of Sexual Behavior, 35,* 739-742.

Loomis, J.M., Klatzky, R.G. Golledge, R.L., Cicinelli, J.G., Pelligrino, J.W., & Fry, P.A. (1993). Nonvisual navigation by blind and sighted: Assessment of path integration ability. *Journal of Experimental Psychology, 122*(1), 73-91.

Loring-Meier, S., & Halpern, D. (1999). Sex differences in visuospatial working memory: Components of cognitive processing. *Psychonomic Bulletin and Review, 6*, 464-471.

Maccoby, E., & Jacklin, C. (1974). *The psychology of sex differences* Stanford, CA: Stanford University Press.

Manning, J., Scutt, D., Wilson, J., & Lewis-Jones, D. (1998). The ratio of 2^{nd} to 4^{th} digit length: A predictor of sperm number and concentrations of testosterone, luteinizing hormaone, and oestrogen. *Human Reproduction (Oxford, England), 13*, 3000-3004.

Mayer, R.E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43-52.

McGee, M.G. (1979). *Human spatial abilities: sources of sex differences* New York, NY: Praeger Press.

Meyer, J.W., Butterick, J., Olkin, M., & Zack, G. (1999). GIS in the K-12 curriculum: A cautionary note. *Professional Geographer, 51*(4), 571-578.

Monmonier, M. (1974). Measures of pattern complexity for choropleth maps. *American Cartographer, 1*, 159-169.

Moreno, R. (2004). Decreasing cognitive load for novice students: Effects of explanatory versus corrective feedback in discovery-based multimedia. *Instructional Science, 32*, 99-113.

Motes, M. A., Malach, R., & Kozhevnikov, M. (2008). Object-processing neural efficiency differentiates object from spatial visualizers. *Neuroreport, 19*(17), 1727-1731.

Nagel, D. (2009). *Partnership Releases 21st Century Skills Maps for Science, Geography*. Retrieved August 28, 2010, from http://thejournal.com/articles/2009/06/30/partnership-releases-21st-century-skills-maps-for-science-geography.aspx

Nash, S.C. (1979). Sex role as a mediator of intellectual functioning. In M.A. Wittig & A.C. Petersen (Eds.), *Sex-related differences in cognitive functioning: Developmental issues* (pp. 263-302). New York, NY: Academic Press.

Natoli, S.J. (1985). Education Daily (January 21, 1985).

Nelson, E. (1995). Color detection on bivariate choropleth maps: The visual search process. *Cartographic, 31*, 33-43.

Nysteun, J.D. (1968). Identification of some fundamental spatial concepts. In B.J.L. Berry & D.F. Marble (Eds.), *Spatial Analysis* (pp. 35-41). Englewood Cliffs, NJ: Prentice-Hall.

Olson, J. (1975). Cognitive cartographic experimentation. *The Canadian Cartographer, 16*, 34-44.

Paas, F.G.W.C., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1-4.

Paas, F.G.W.C., Tuovinen, J.E., Tabbers, H., & Van Gerven, P.W.M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63-71.

Paas, F.G.W.C., & Van Gog, T. (2006). Optimizing worked example instruction: Different ways to increase germane cognitive load. *Learning and Instruction, 16*, 87-91.

Paas, F.G.W.C., & Van Merrienboer, J.J.G. (1994). Instructional control of cognitive load in the training of complex cognitive tasks. *Educational Psychology Review, 6*(4), 351-371.

Paas, F.G.W.C., Van Merrienboer, J.J.G., & Adam, J.J. (1994). Measurement of cognitive load in instructional research. *Perceptual and Motor Skills, 79*, 419-430.

Palladino, S. (1994). *A role for geographic information systems in the secondary schools: An assessment of the current status and future possibilities*. Master's thesis, Department of Geography, University of California at Santa Barbara, Santa Barbara, CA.

Patterson, M.W., Reeve, K., & Page, D. (2003). Integrating geographic information systems into the secondary curricula. *Journal of Geography, 102*, 275-281.

Renkl, A., & Atkinson, R.K. (2003). Structuring the transition from example study to problem solving in cognitive skill acquisition: A cognitive load perspective. *Educational Psychologist, 38*(1), 15-22.

Roder, W. (1977). An alternate interpretation of men and women in geography. *The Professional Geographer, 29*, 397-400.

Rutherford, D. (2007) *Key Geography Education Indicators: The U.S. Is Being Left Behind*. Retrieved August 17, 2010, from http://www.nationalgeographic.com/foundation/pdf/KeyGeographyEducationIndicators.pdf

Salden, R.J.C.M., Paas, F., Broers, N.J., & Van Merrienboer, J.J.G. (2004). Mental effort and performance as determinants for the dynamic selection of learning tasks in air traffic control training. *Instructional Science, 32*, 153-172.

Salden, R.J.C.M., Paas, F.G.W.C., & Van Merrienboer, J.J.G. (2006). A comparison of approaches to learning task selection in the training of complex cognitive skills. *Computers in Human Behavior*, *22*, 321-333.

Sarnoff, H. (2000). Census 1790: A GIS project. *Computers in the Social Studies* 8(1).

Saucier, D., McCreary, D., & Saxberg, J. (2002). Does gender role socialization mediate sex differences in mental rotations? *Personality and Individual Differences, 32*, 1101-1111.

Schwartz, N., Ellsworth, L., Graham, L., & Knight, B. (1998). Accessing prior knowledge to remember text: A comparison of advanced organizers and maps. *Contemporary Educational Psychology, 23*, 65-89.

Sherman, J.A. (1978). *Sex-related cognitive differences: An essay on theory and evidence* Springfield, IL: Charles C. Thomas.

Shirey, R.I. (1994). *The importance of geography in the school curriculum*. (Report No. SO-028-726). Indiana, PA: Indiana University of Pennsylvania, National Council for Geographic Education. ERIC Document ED420575.

Signorella, M., & Jamison, W. (1986). Masculinity, femininity, androgyny, and cognitive performance: A meta-analysis. *Psychological Bulletin, 100*, 207-228.

Slotnick, S., & Moo, L. (2006). Prefrontal cortex hemispheric specialization for categorical and coordinate visual spatial memory. *Neuropsychologia, 44*, 1560-1568.

Stringer, P. (1973). Color and base in urban planning maps. *The Cartographic Journal, 10*, 89-94.

Subrahmanyam, K., & Greenfield, P.M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of Applied Developmental Psychology, 15*, 13-32.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

Sweller, J. (2004). Instructional design consequences of an analogy between evolution by natural selection and human cognitive architecture. *Instructional Science, 32*, 9-31.

Sweller, J., Chandler, P., Tierney, P., & Cooper, M. (1990). Cognitive load and selective attention as factors in the structuring of technical material. *Journal of Experimental Psychology: General, 119*, 176-192.

Sweller, J., Van Merrienboer, J.J.G., & Paas, F.G.W.C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Terlecki, M.S., & Newcombe, N.S. (2005). How important is the digital divide? The realtion of computer and videogame usage to gender differences in mental rotation ability. *Sex Roles, 53*, 433-441.

Terlecki, M.S., Newcombe, N.S., & Little, M. (2007). *Durable and generalized effects of spatial experience on mental rotation: Gender differences in growth patterns. Applied Cognitive Psychology* Hoboken, NJ:Wiley InterScience.

Tuan, Y. (1975). Images and mental maps. *Annals of the Association of American Geographers*, *65*(2), 205-213.

Tuovinen, J., & Paas, F. (2004). Exploring multidimensional approaches to the efficiency of instructional conditions. *Instructional Science, 32*, 133-152.

Turner, M.L., & Engle, R.W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154.

Van Merrienboer, J.J.G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training* Englewood Cliffs, NJ: Educational Technology Publications.

Van Merrienboer, J.J.G., Clark, R.E., & deCroock, M.B.M. (2002). Blueprints for complex learning: The 4C/ID-model. *Educational Technology, Research and Development*, *50*(2), 39-64.

Van Merrienboer, J.J.G., Jelsma, O., & Paas, F.G.W.C. (1992). Training for reflective expertise: A four-component instructional design model for training complex cognitive skills. *Educational Technology, Research and Development*, *40*(2), 23-43.

Van Merrienboer, J.J.G., Kirschner, P.A., & Kester, L. (2003). Taking the load off a learner's mind: Instructional design for complex learning. *Educational Psychologist, 38*(1), 5-13.

Voyer, D., Voyer, S., & Bryden, M. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*, 250-270.

Wachs, T.D. (1992). *The nature of nurture* Newbury Park, CA: Sage.

Wanner, S., & Kerski, J. (2000). *Fits, Starts, and Headway: The implementation of geographic information systems technology and methods in beginning and advanced high school geography courses*. Retrieved August 28, 2010, from http://rmmcweb.cr.usgs.gov/public/outreach/headway.html

APPENDIX A.

ASSENT FORM

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO

ASSENT Form

Study Title: Instructional Geographic Information Science and Map Overlay.

My name is Thomas Tricot.

What is this about?

I would like to talk to you about the ability of students like you to understand and be able to learn complex spatial concepts, or the ability to understand a mental image of your environment. I want to learn whether or not it is possible for middle school students to learn complex spatial concepts.

Did my parents say it was ok?

Your parent(s) said it was ok for you to be in this study and have signed a form like this one.

Why me?

We would like you to take part because you are between the ages of 12 and 14.

What if I want to stop?

You do not have to say "yes", if you do not want to take part. We will not punish you if you say "no". Even if you say "yes" now and change your mind after you start doing this study, you can stop and no one will be mad at you.

What will I have to do?

You will receive a 10 minute period of instruction where you will be asked to look at a series of diagrams that depict overlapping areas. During this instructional period, you will have the opportunity to ask questions about the diagrams. Immediately following the instructional period, you will take a test to evaluate your level of understanding. The test will consist of a series of similar diagrams and a list of possible answers. The test will take approximately 20 minutes. This entire instructional and testing procedure will be conducted once a week for six weeks.

Will anything bad happen to me?

There is nothing bad that will happen to you.

Will anything good happen to me?

You may acquire knowledge of the spatial concept called "map overlay". An understanding of complex spatial concepts may help you gain a better understanding of the world you live in.

Do I get anything for being in this study?

There are no costs to you or payments to you as a result of participation in this study.

What if I have questions?

You are free to ask questions at any time.

If you understand this study and want to be in it, please write your name below.

______________________ ______

Signature of child Date

APPENDIX B.

CONSENT FORM

UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
CONSENT FOR A MINOR TO ACT AS A HUMAN PARTICIPANT: Long Form

Project Title: Instructional Geographic Information Science and Map Overlay

Project Director: Thomas Tricot

Participant's Name: ____

What is the study about?
This study involves research on the ability of children to understand complex spatial concepts (the ability to understand a mental image of their environment). The purpose of this study is to determine whether middle-school aged children are able to learn the concepts necessary for this type of understanding. Your child meets the criteria to participate in this study.

Why are you asking my child?
Your child is being asked to participate in this study because he/she is between the ages of 12 and 14. Research suggests that children of this age range show the ability to demonstrate complex spatial reasoning about their environment.

What will you ask my child to do if I agree to let him or her be in the study?
Participants in the study will receive a 10 minute period of instruction where he/she will be asked to look at a series of diagrams that depict overlapping areas. During this instructional period, he/she will have the opportunity to ask questions about the diagrams. Immediately following the instructional period, participants will take a test to evaluate their level of understanding. The test will consist of a series of similar diagrams and a list of possible answers. The test will take approximately 20 minutes. This entire instructional and testing procedure will be conducted once a week for six weeks. This repetitive instruction and testing procedure is critical to the determination of whether these complex spatial concepts are being learned, as opposed to being memorized.

What are the dangers to my child?
The Institutional Review Board at the University of North Carolina at Greensboro has determined that participation in this study poses no risk to participants.

If you have any concerns about your child's rights or how you are being treated, please contact Eric Allen in the Office of Research and Compliance at UNCG at (336) 256-1482. Questions about this project or benefits or risks associated with being in this study can be answered by Dr. Rick Bunch who may be contacted at (336) 334-3916 (rlbunch@uncg.edu) or Thomas Tricot at (336) 883-3250 (tatricot@uncg.edu).

Are there any benefits to my child as a result of participation in this research study?
Participants in this study may acquire knowledge of the map overlay concept. Participants may also begin a process of learning complex spatial concepts.

Are there any benefits to society as a result of my child taking part in this research?
An understanding of complex spatial concepts may help students gain a better understanding of

the world they live in. The findings of this research may help students to become exposed to spatial concepts at a younger age.

Will my child get paid for being in the study? Will it cost me anything for my kid to be in this study?
There are no costs to you or payments to you or your child as a result of participation in this study.

How will my child's information be kept confidential?
The names of participants will not be known. Participants will be given a unique identification number to be used throughout the study. The identification number will not be linked to any personal information. No personal information will be collected. All data and consent forms will be stored in a locked file cabinet in the office of the Geography Department at the University of North Carolina at Greensboro. All information obtained in this study is strictly confidential unless disclosure is required by law.

What if my child wants to leave the study or I want him/her to leave the study?
You have the right to refuse to allow your child to participate or to withdraw him or her at any time, without penalty. If your child does withdraw, it will not affect you or your child in any way. If you or your child chooses to withdraw, you may request that any data which has been collected be destroyed unless it is in a de-identifiable state.

What about new information/changes in the study?
If significant new information relating to the study becomes available which may relate to your willingness to allow your child to continue to participate, this information will be provided to you.

Voluntary Consent by Participant:
By signing this consent form, you are agreeing that you have read it or it has been read to you, You fully understand the contents of this document and consent to your child taking part in this study. All of your questions concerning this study have been answered. By signing this form, you are agreeing that you are the legal parent or guardian of the child who wishes to participate in this study described to you by Thomas Tricot.

__________________________________ Date: _______________
Participant's Parent/Legal Guardian's Signature

__________________________________ Date: _______________
Participant's Parent/Legal Guardian's Signature

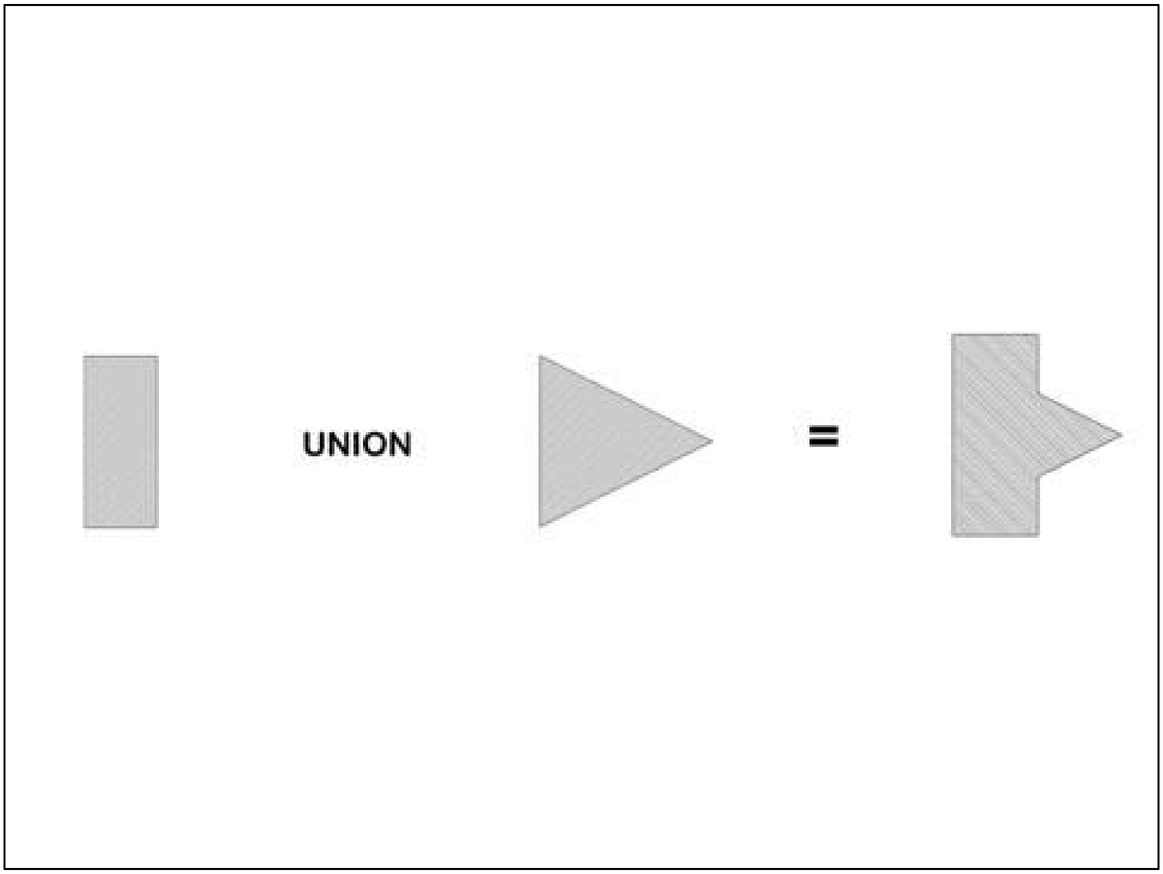
APPENDIX C.

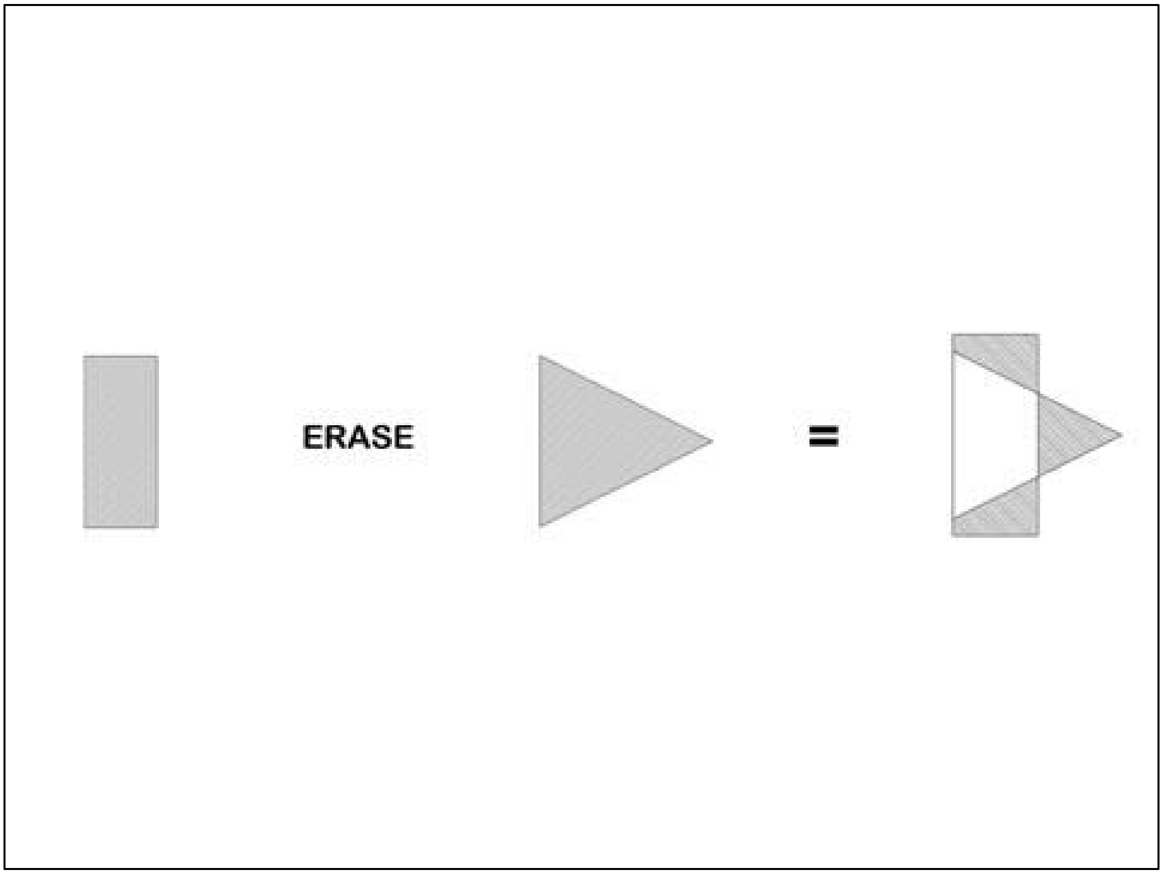
PRE-TEST INSTRUCTION

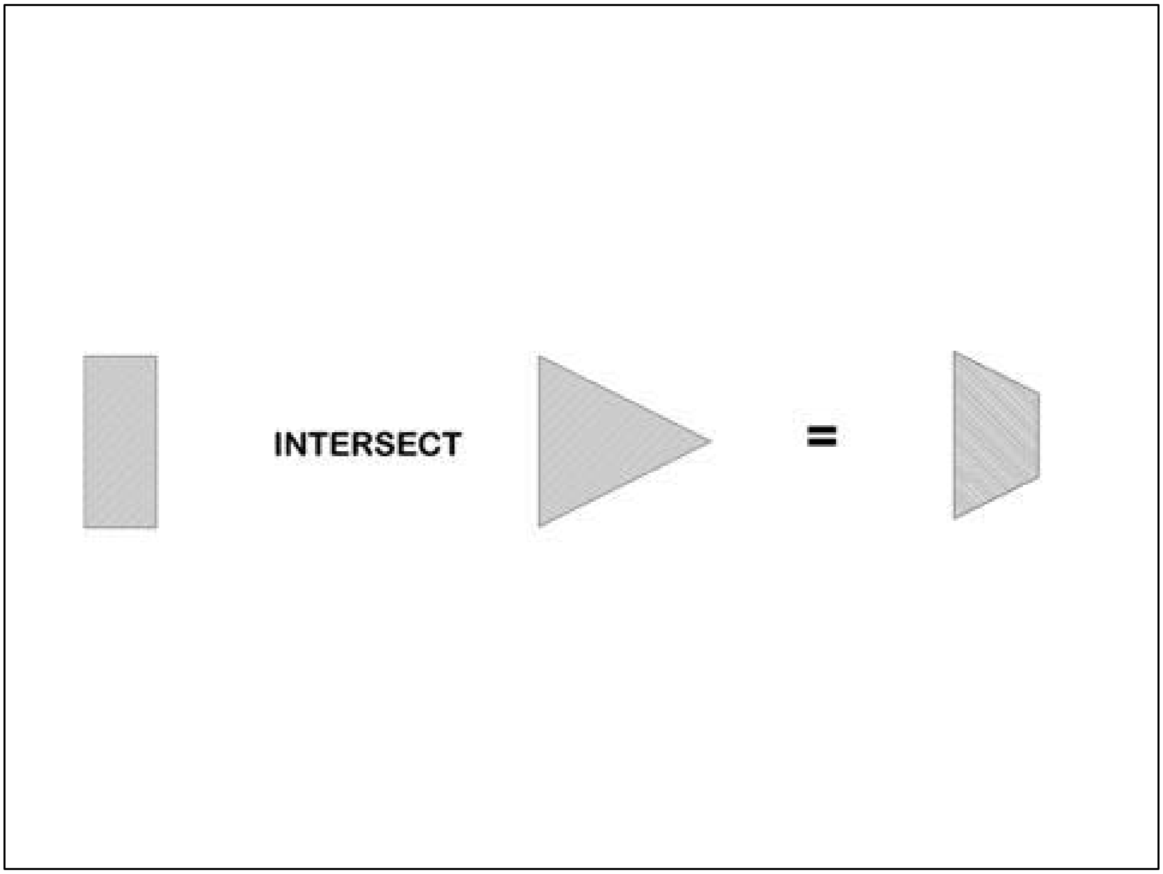
The **ERASE** function is when spatially alike areas of two or more features are deleted from each feature resulting in the preservation of areas not common to all features.

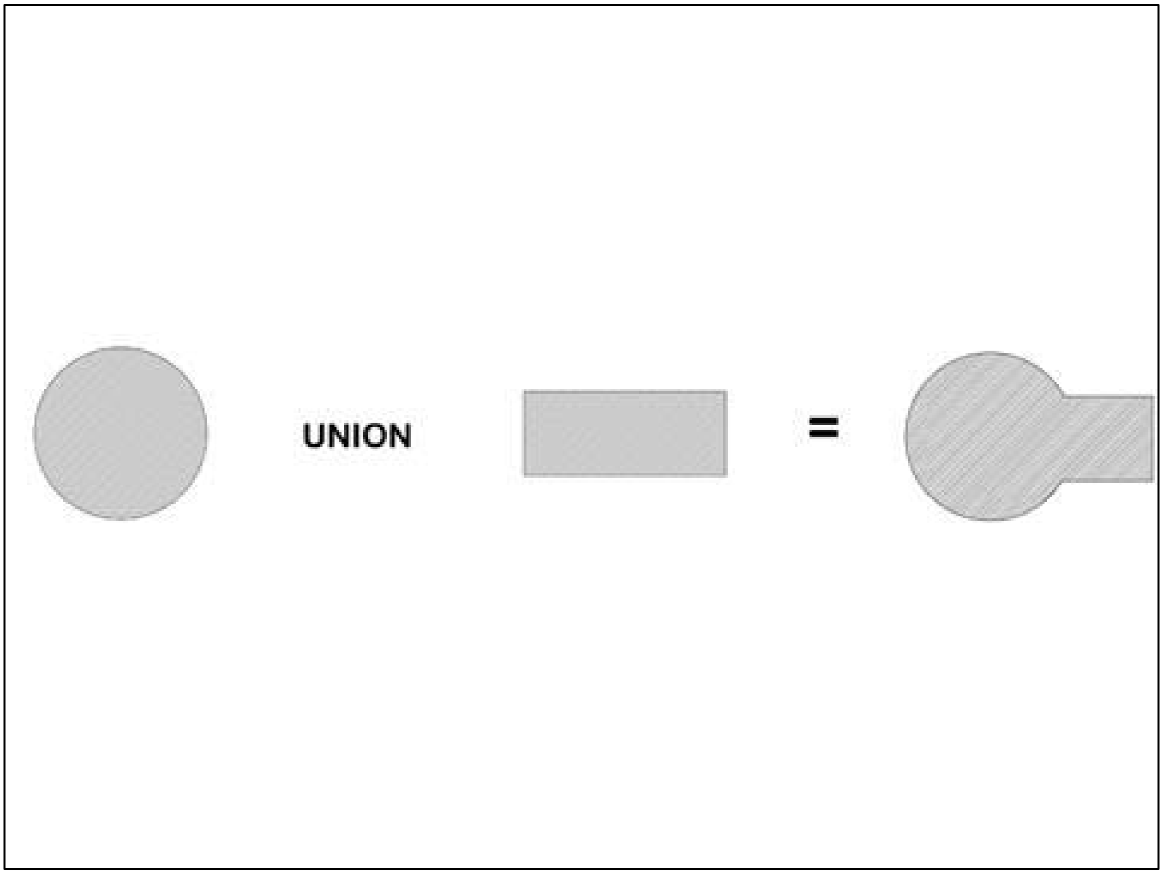
The **INTERSECT** function is when spatially alike areas of two or more features are combined into one feature representing the spatially alike area and attributes of each feature found within.

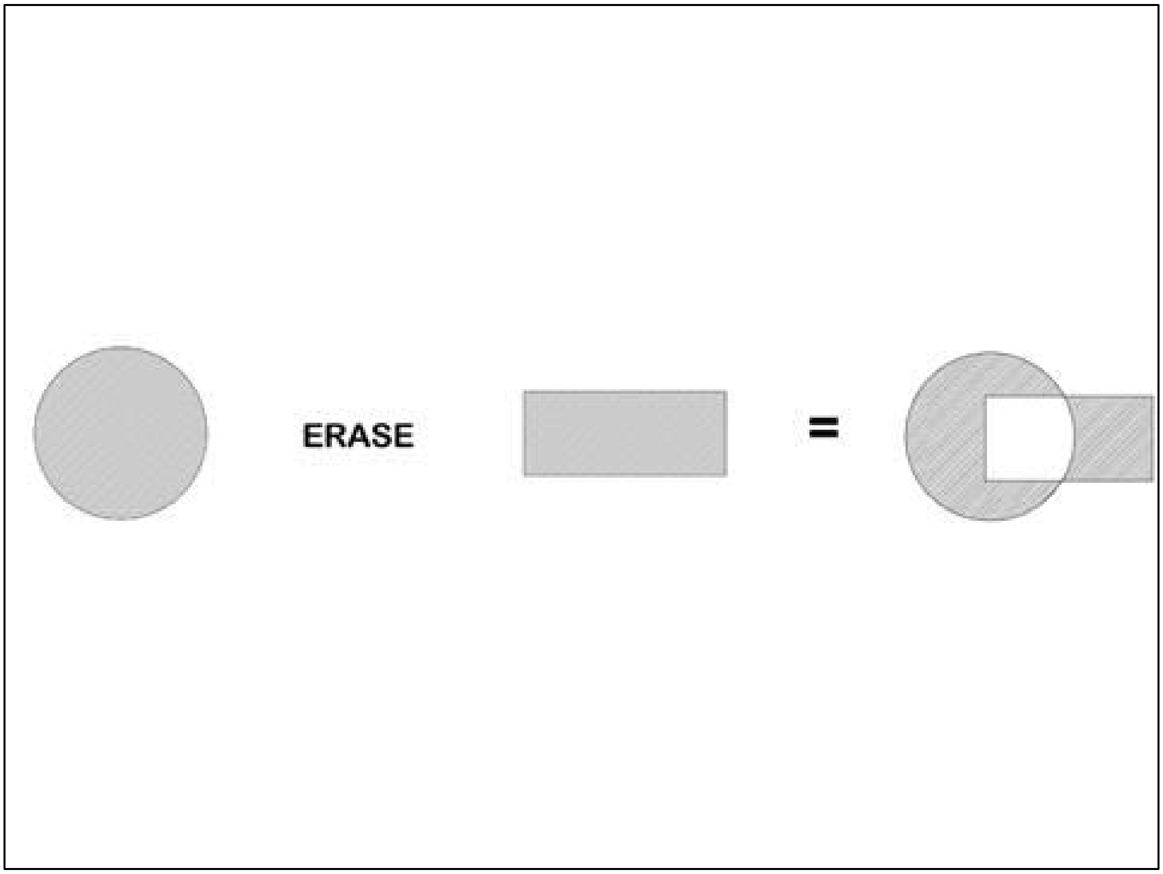
The **UNION** function is when areas of two or more features are combined into one feature representing the area of a common attribute of each feature found within.

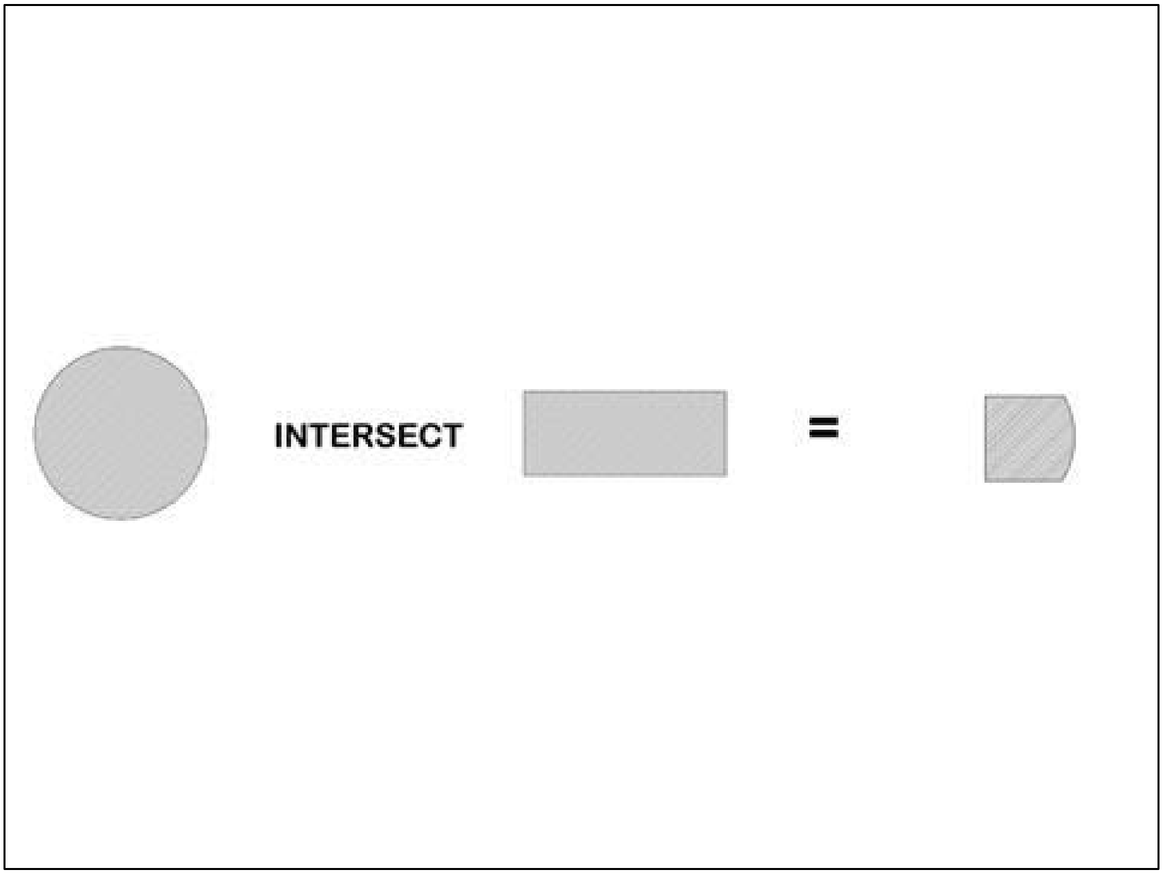

UNION
=

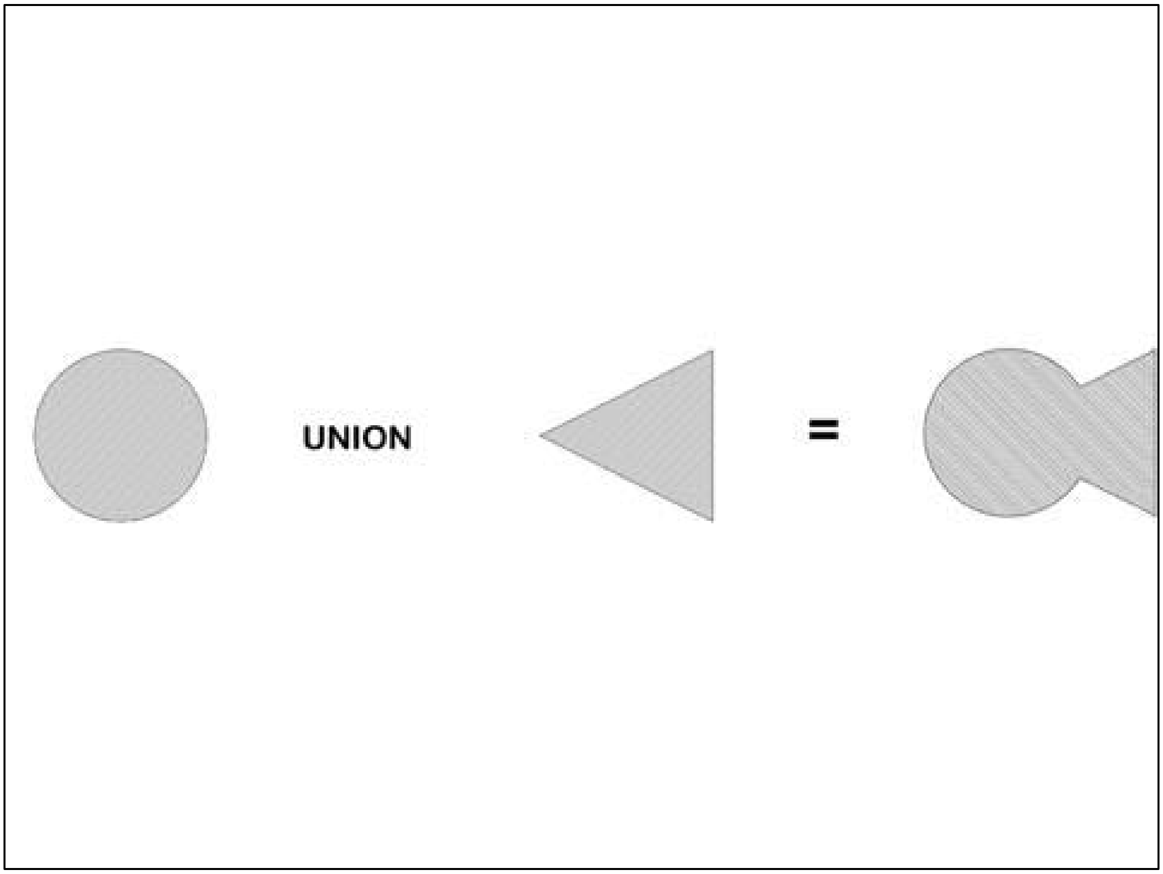

ERASE
=

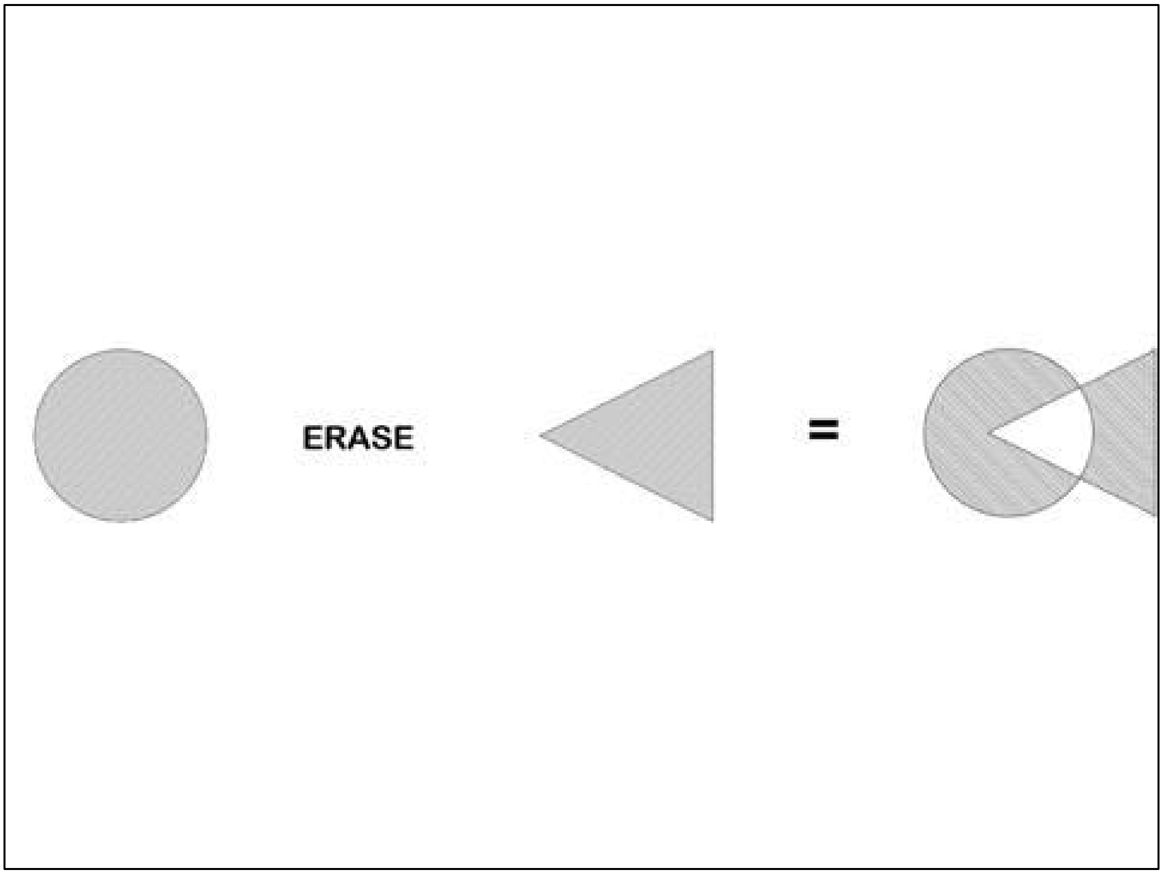

INTERSECT
=

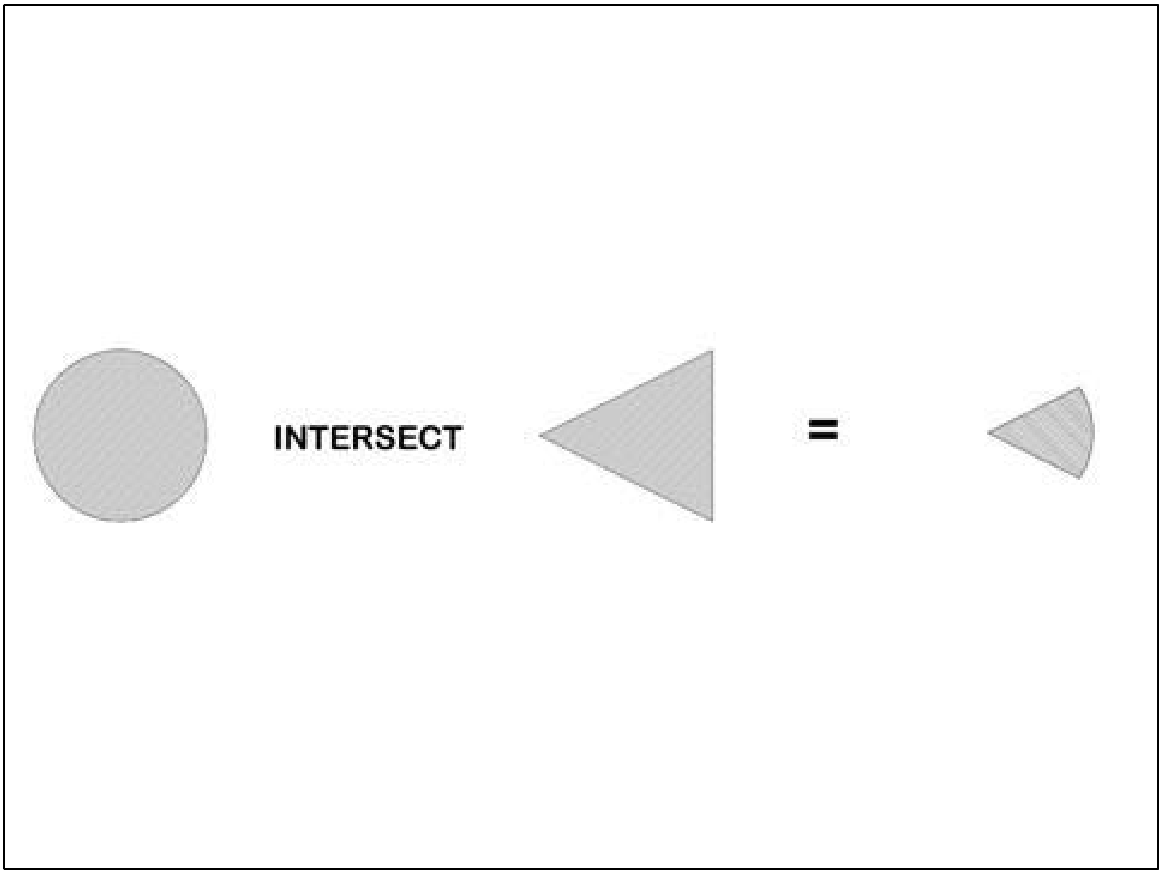

UNION
=

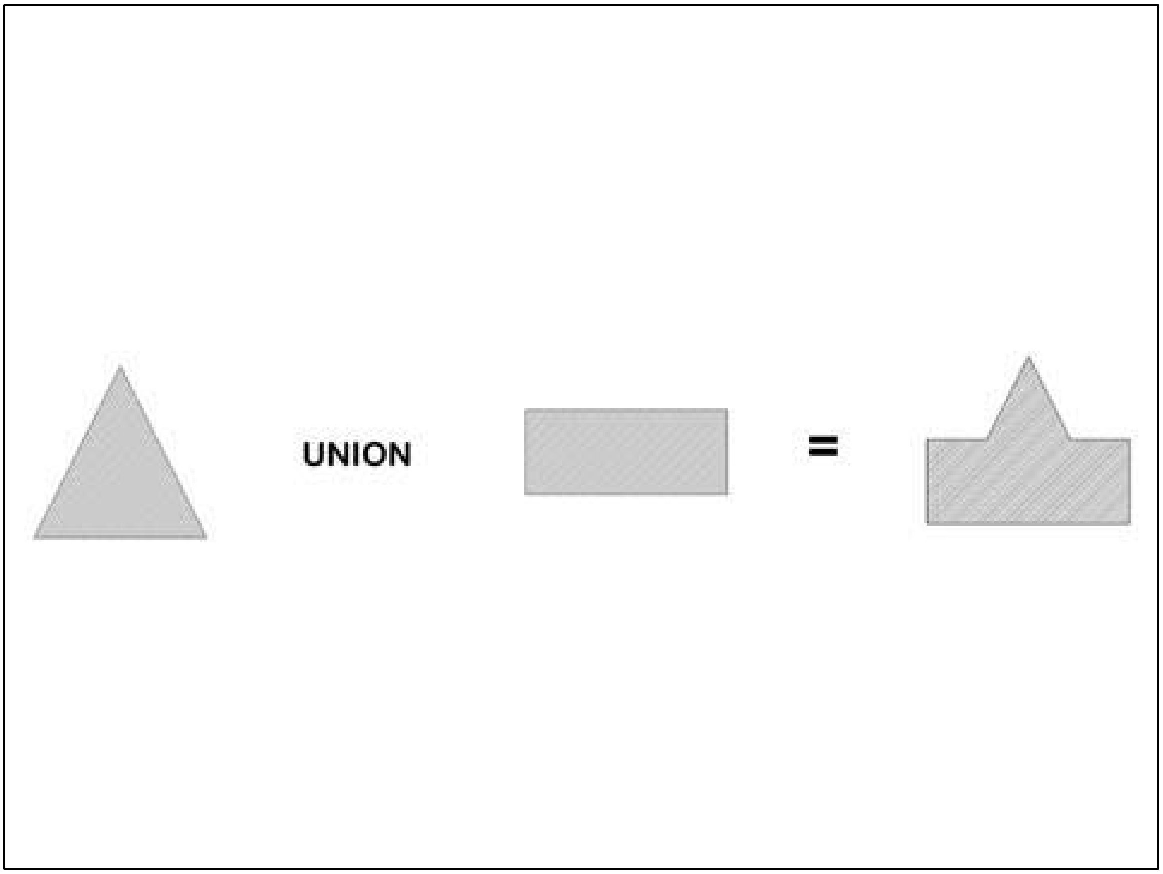

ERASE
=

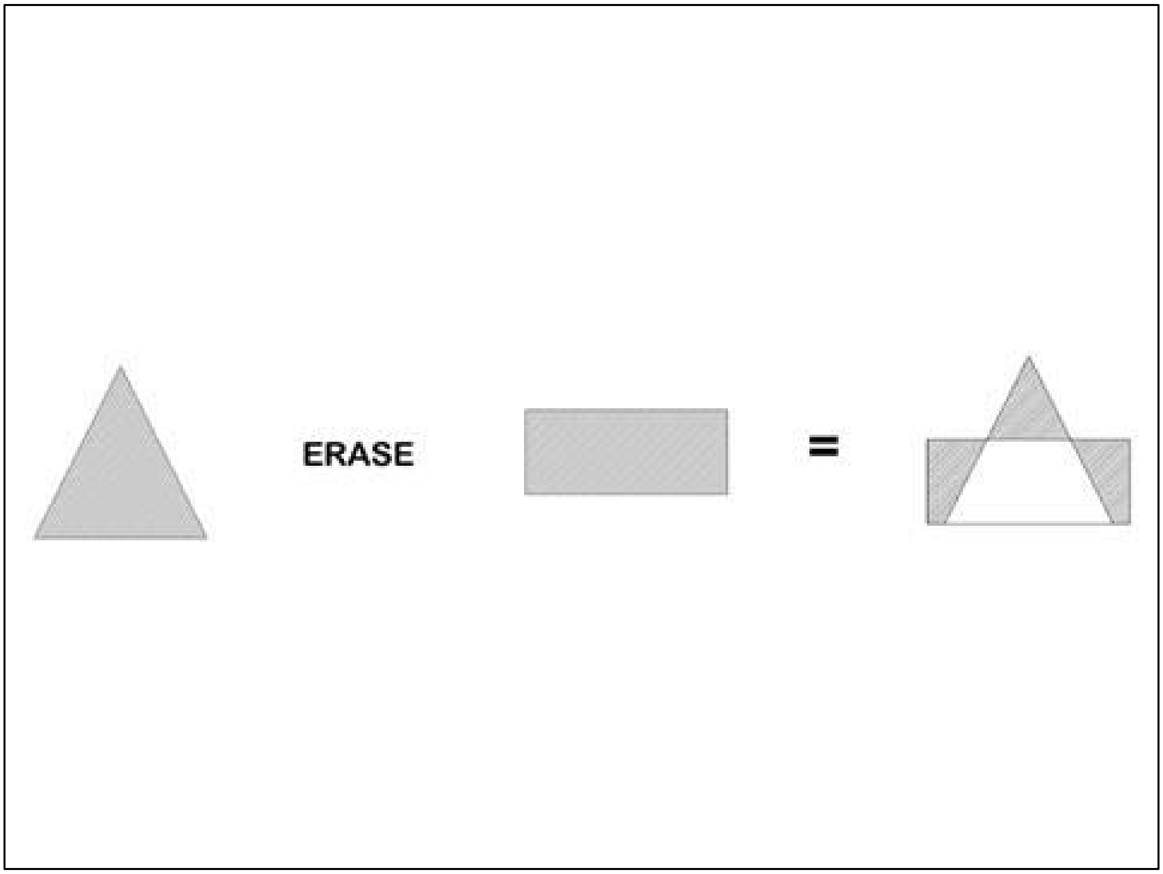

INTERSECT
=

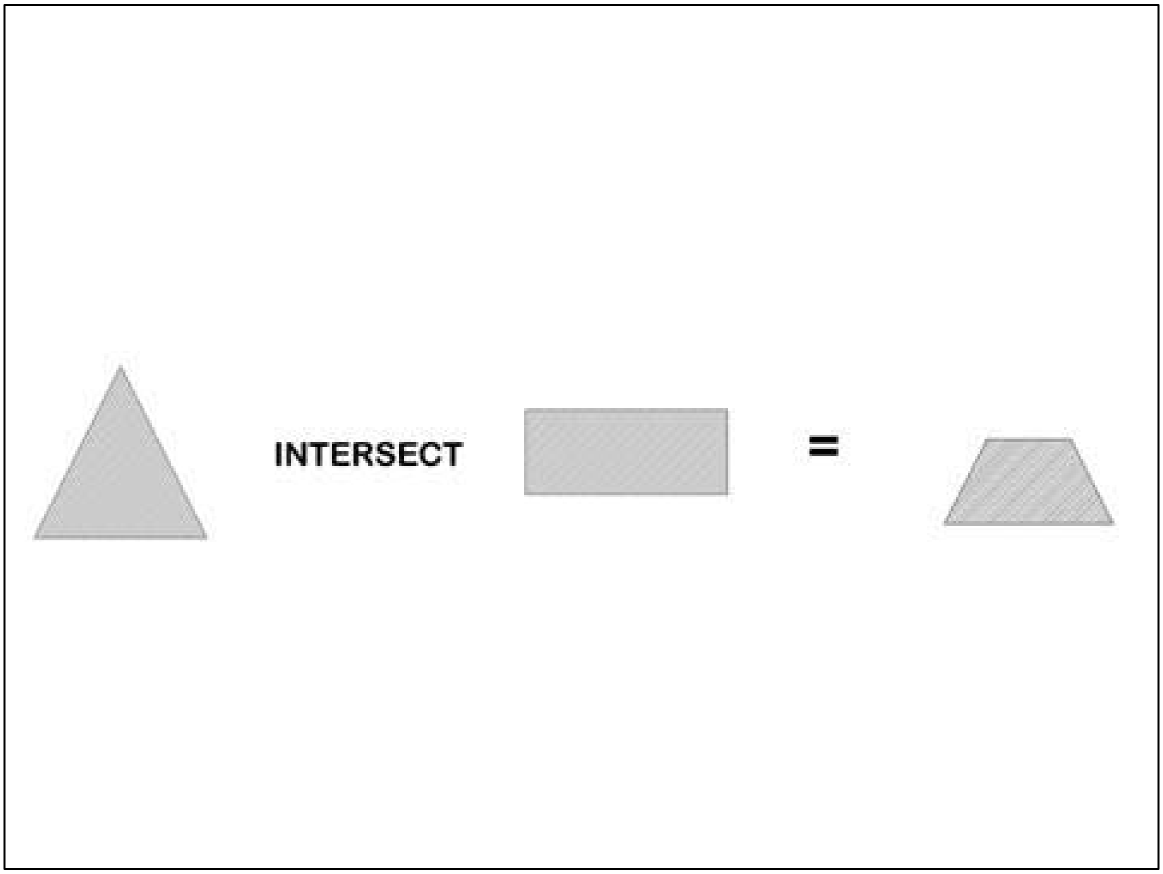

UNION
=

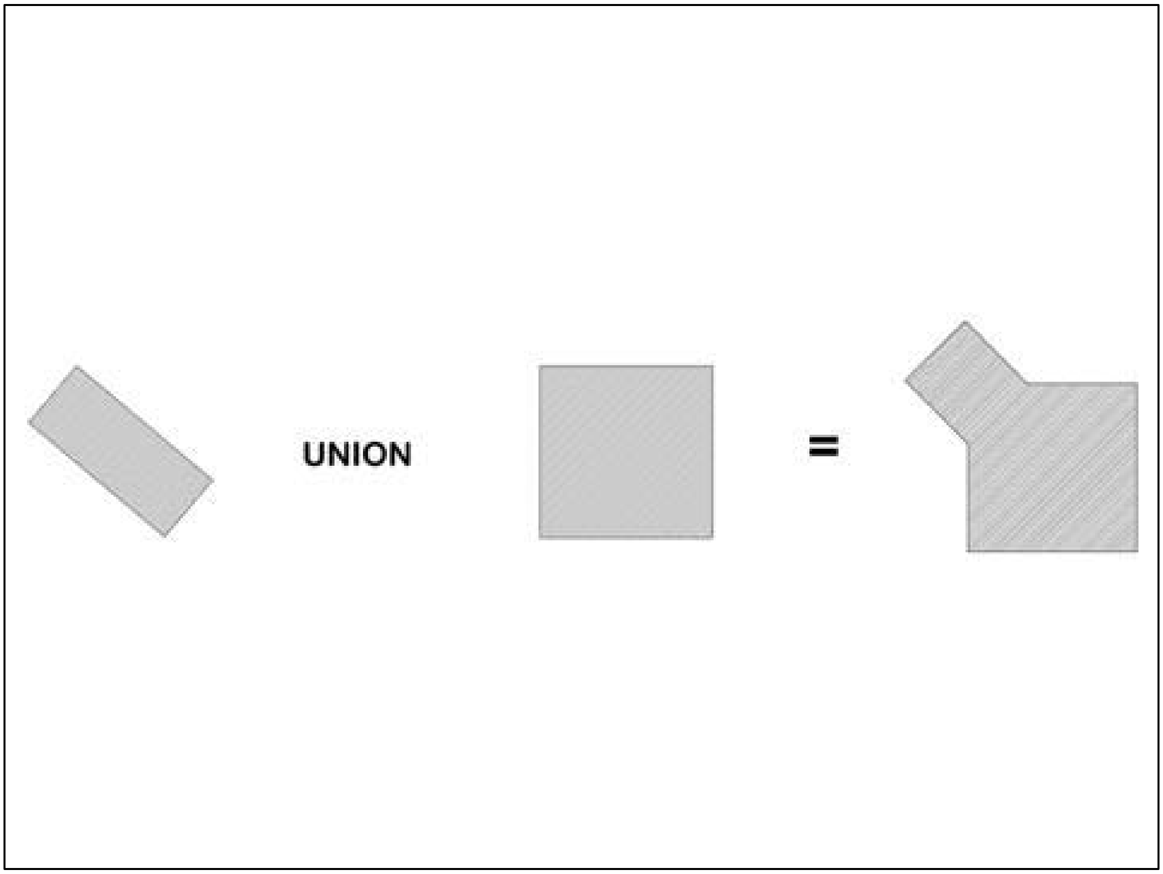

ERASE
=

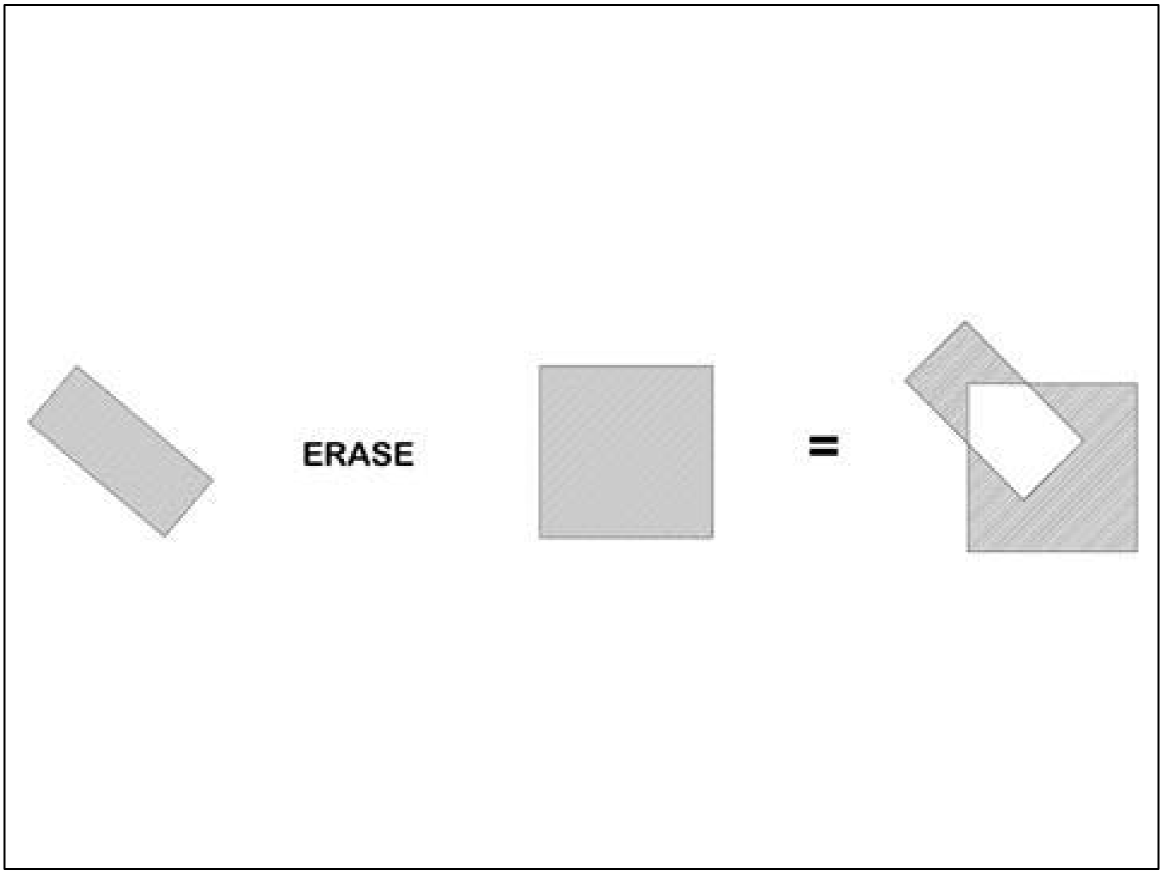

INTERSECT
=

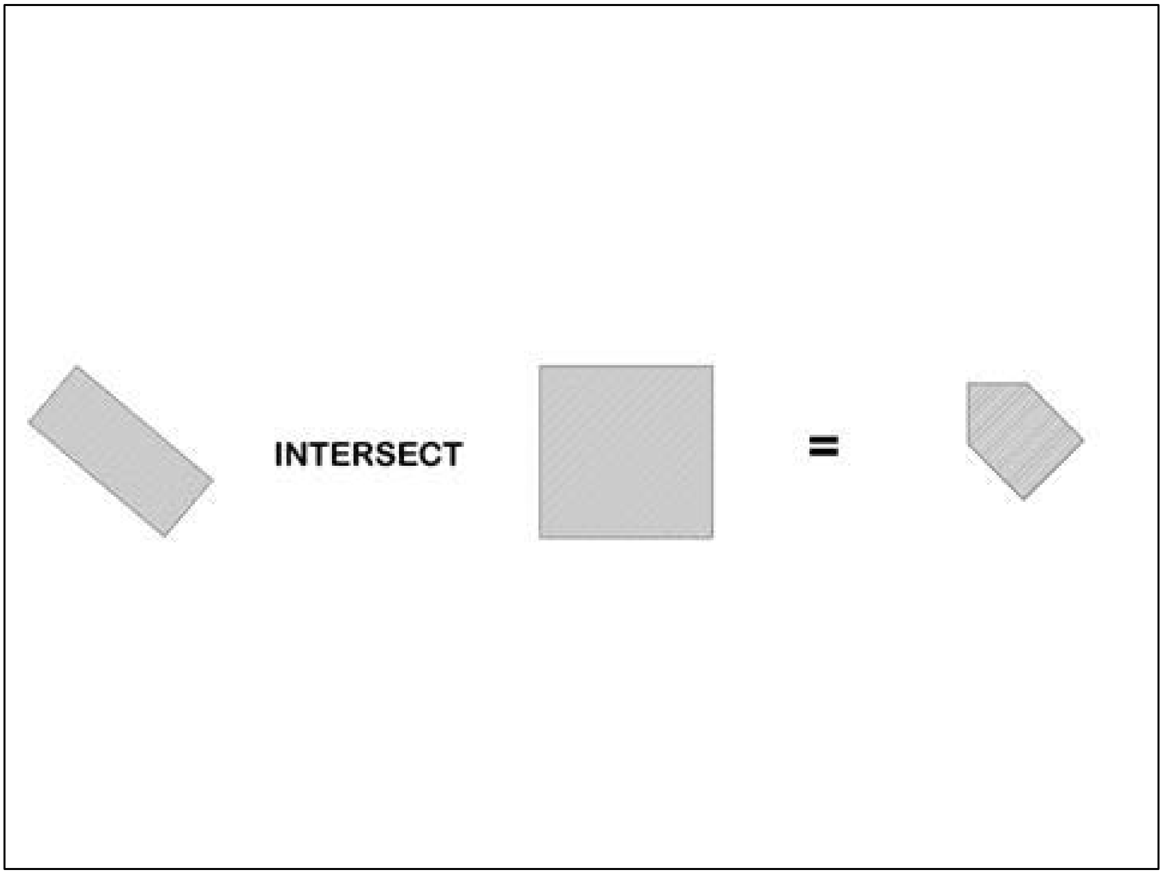

UNION
=

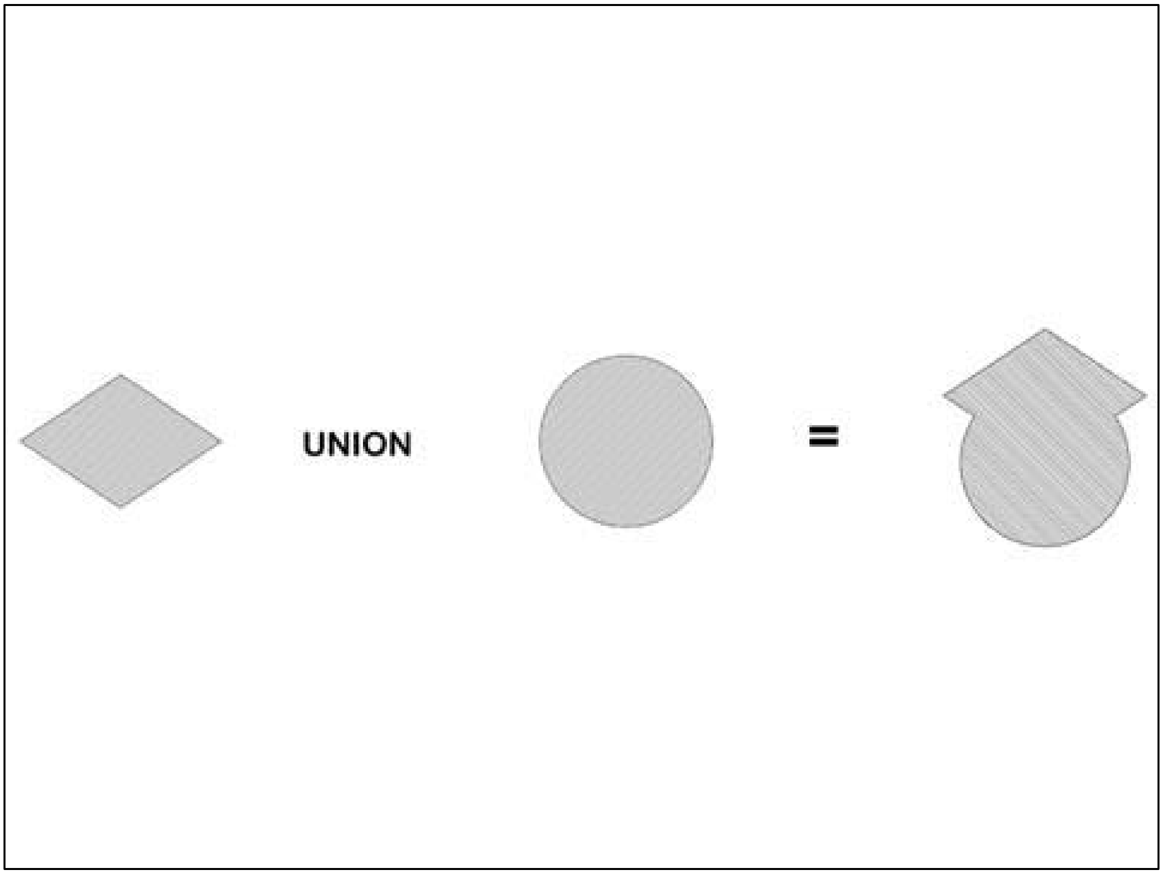

ERASE
=

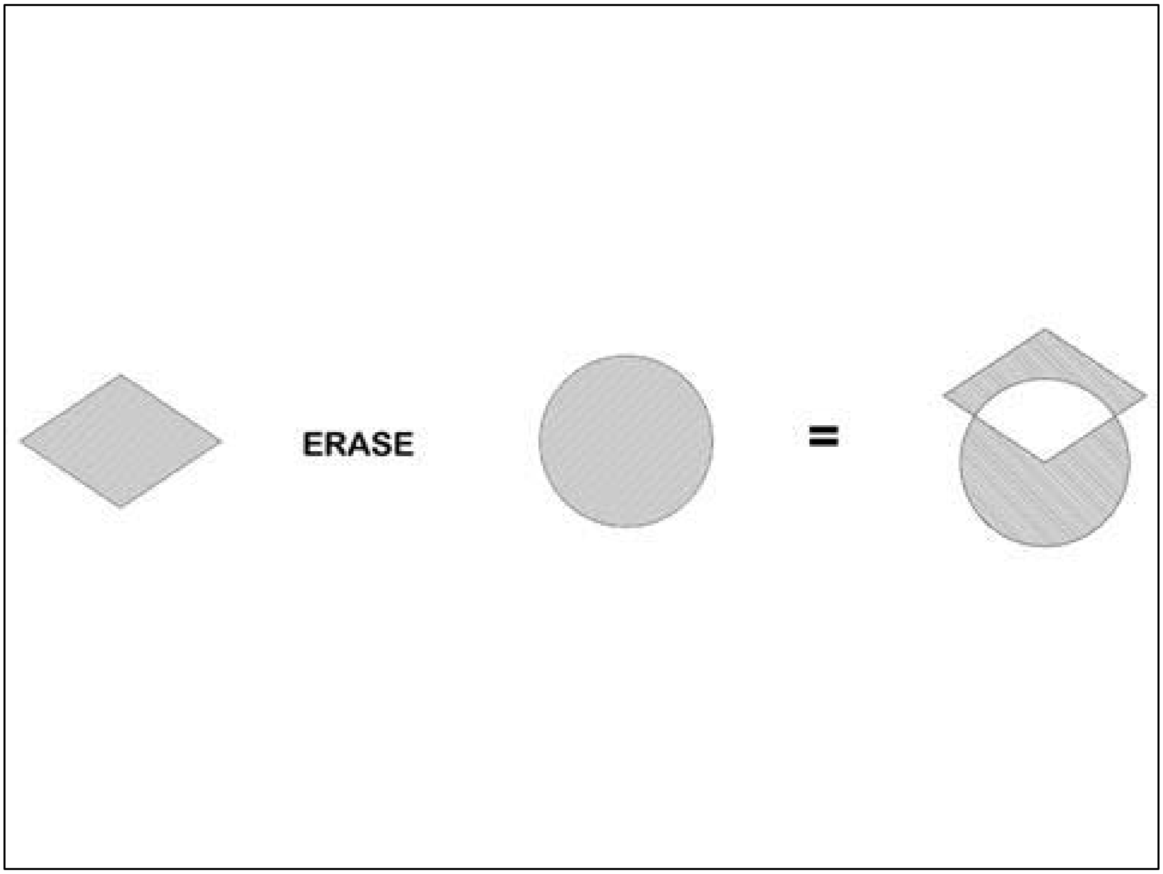

INTERSECT
=

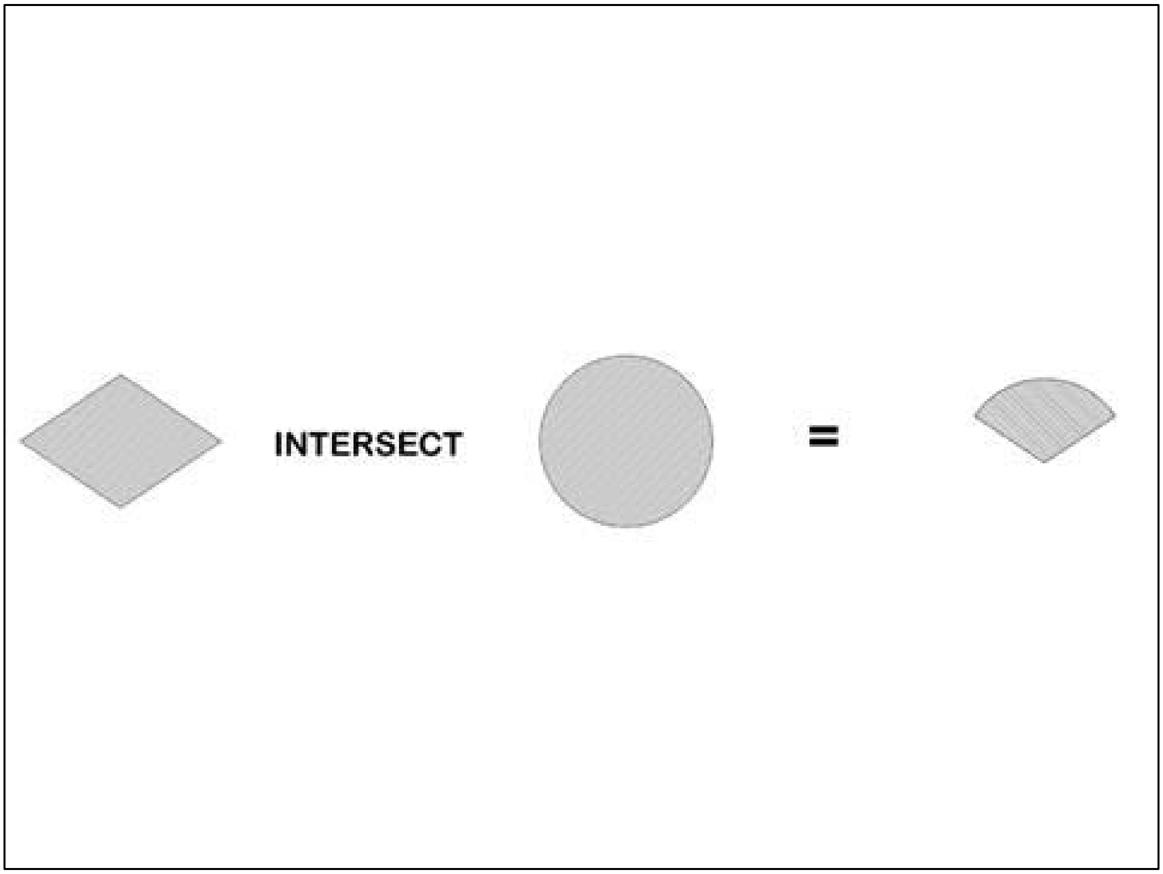

UNION
=

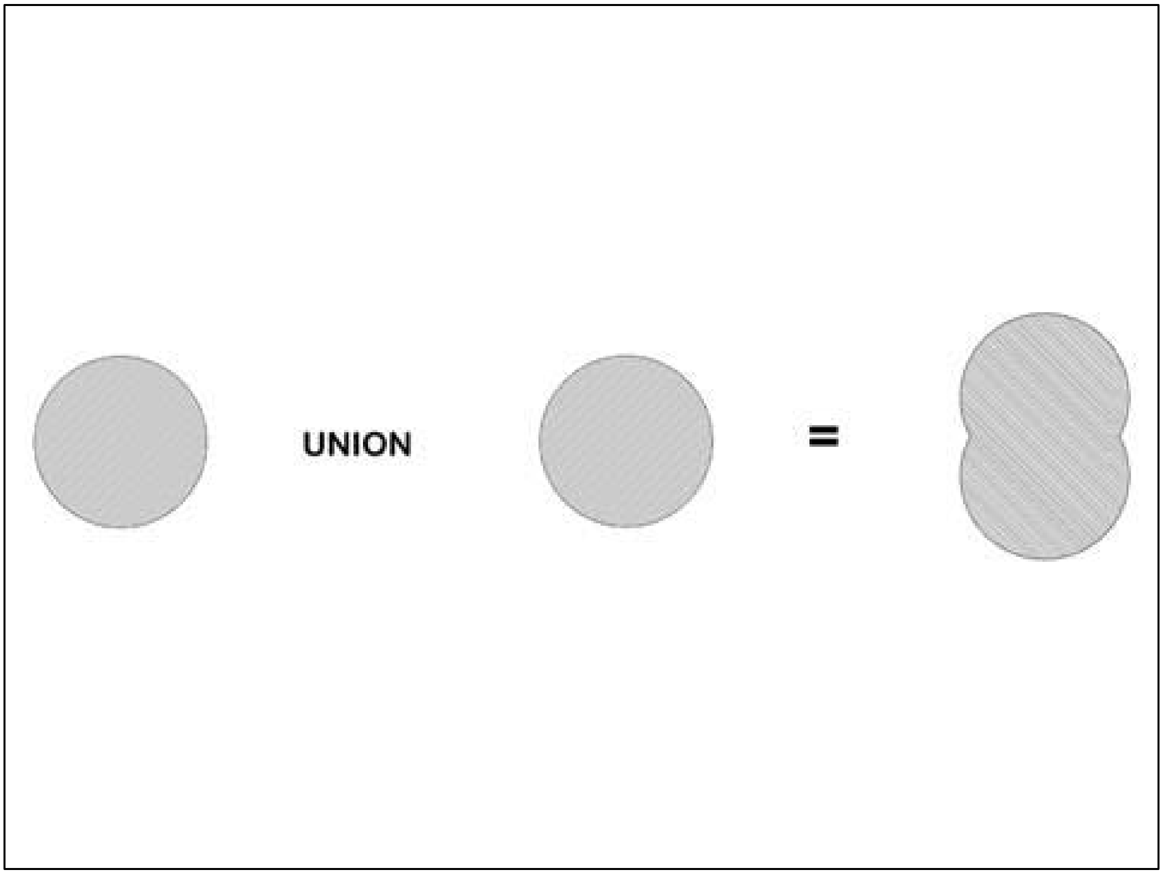

ERASE
=

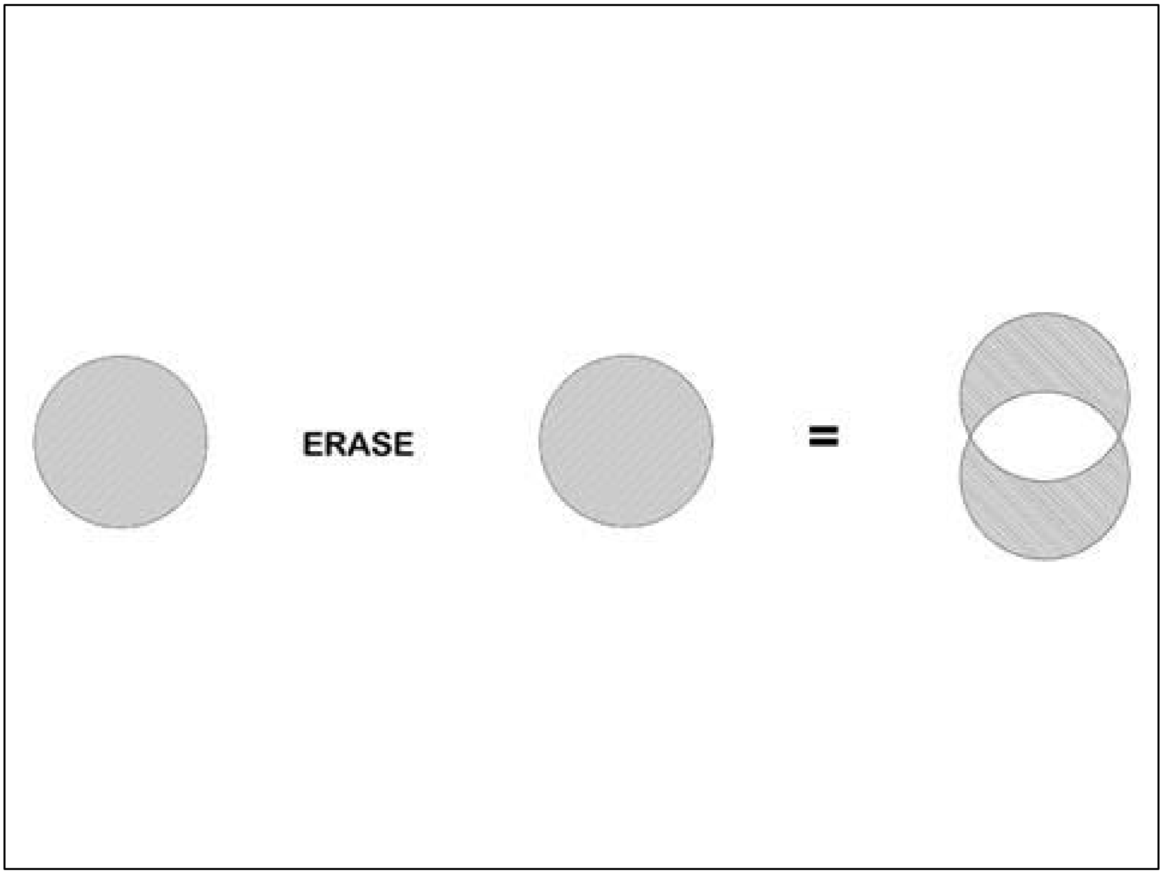

INTERSECT
=

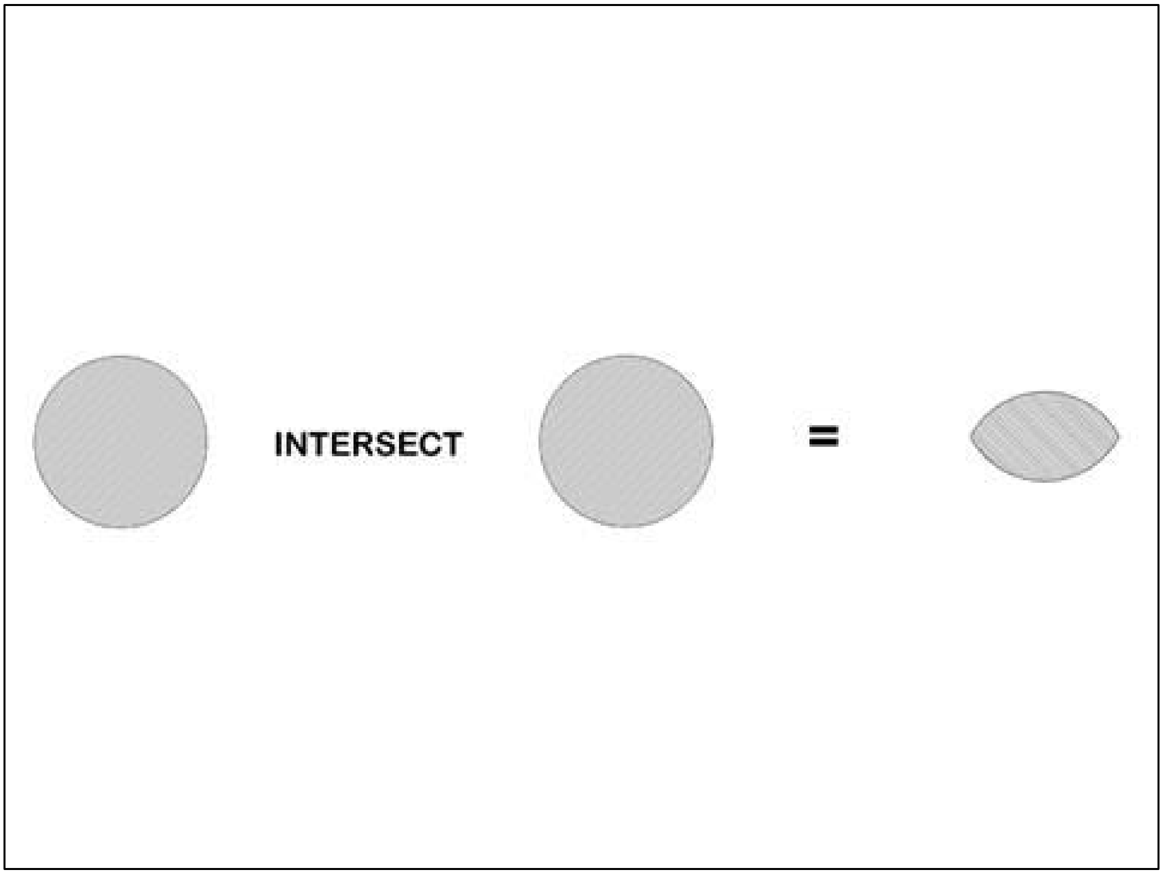

UNION
=

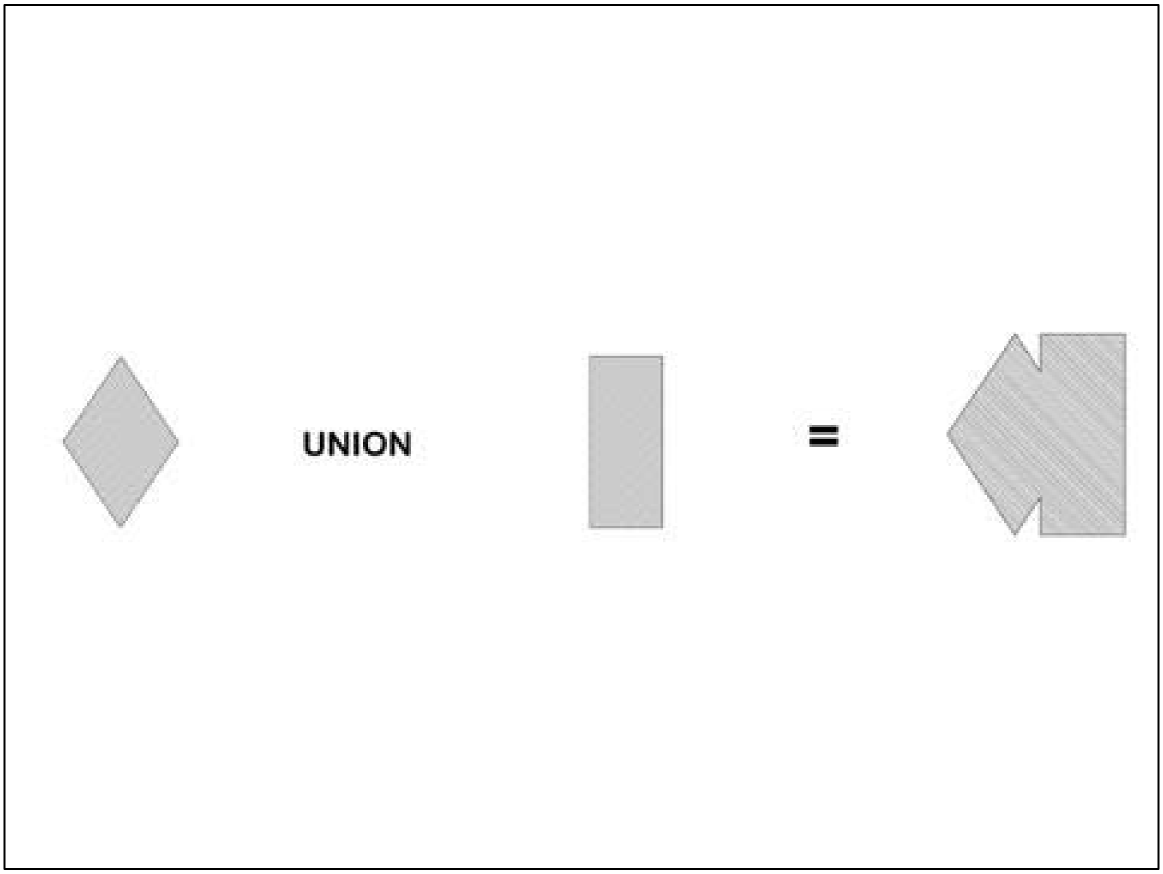

ERASE
=

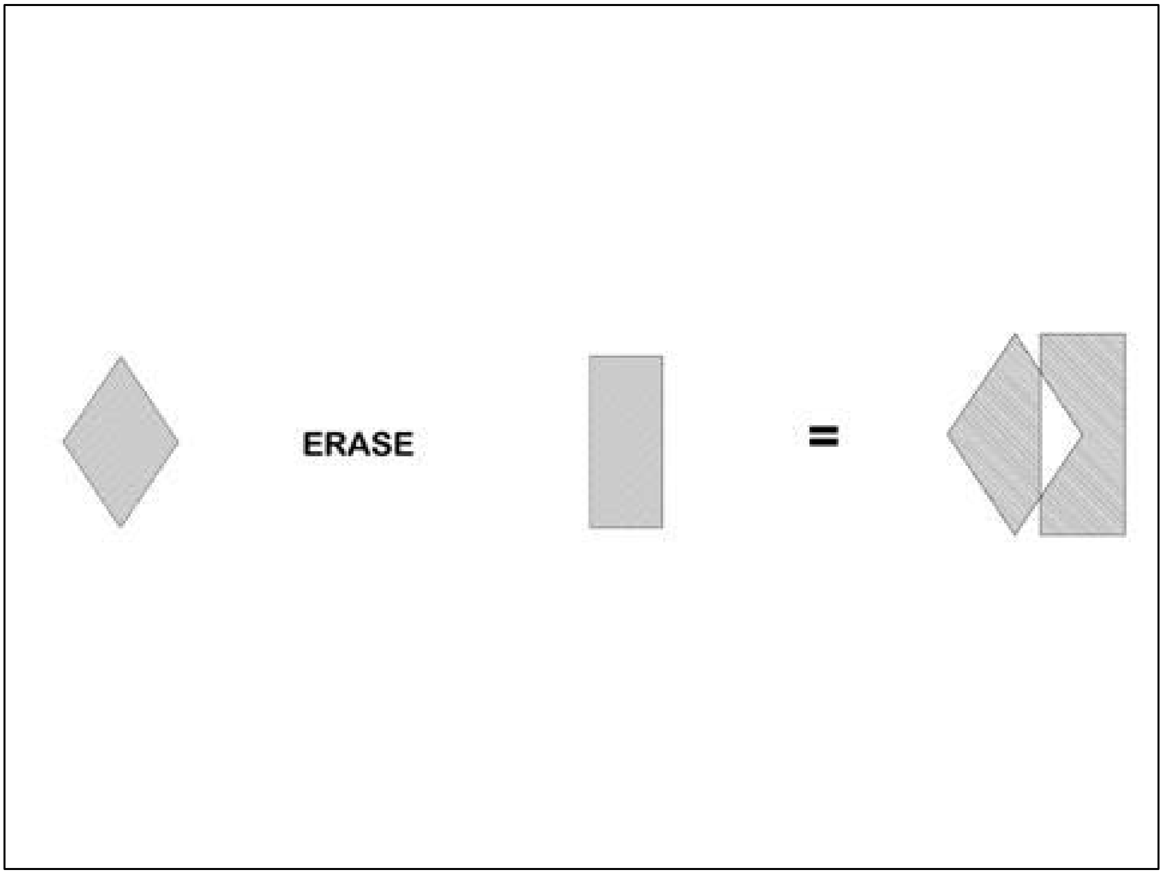

INTERSECT
=

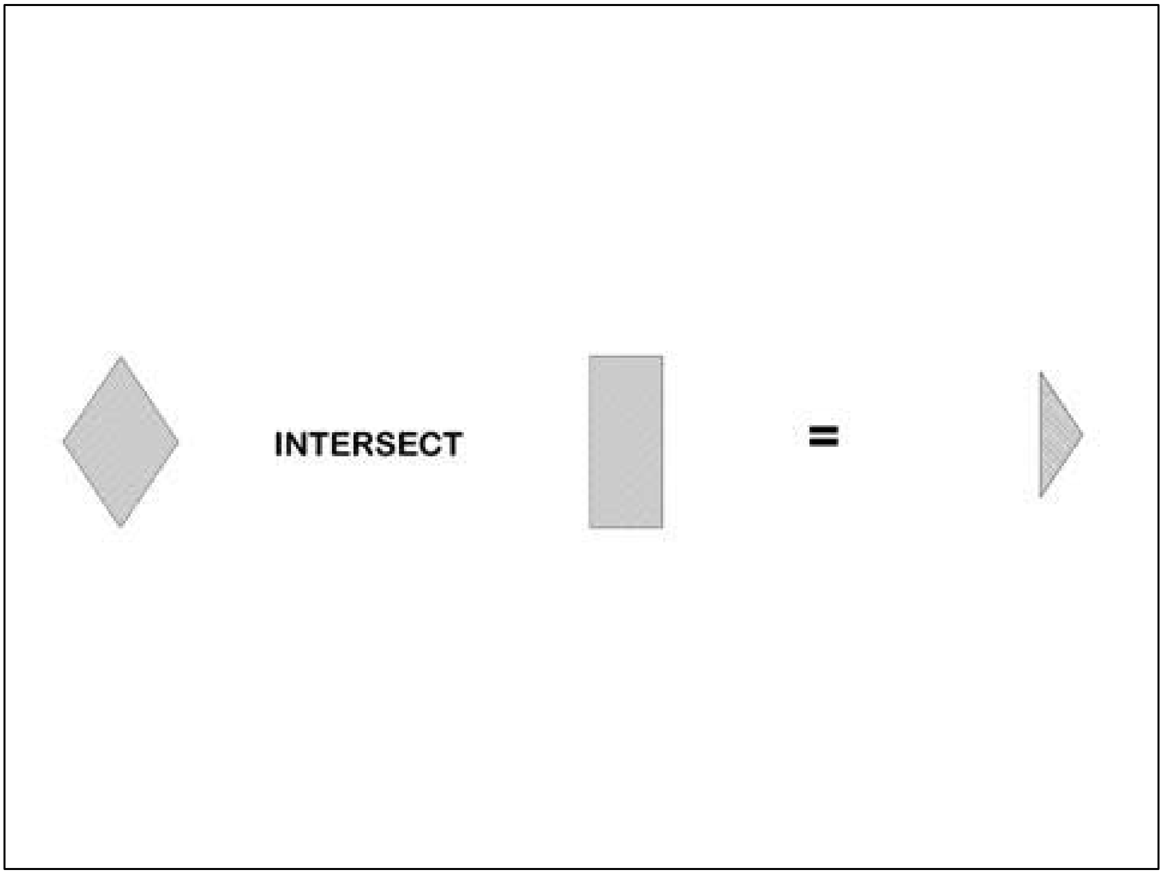

UNION
=

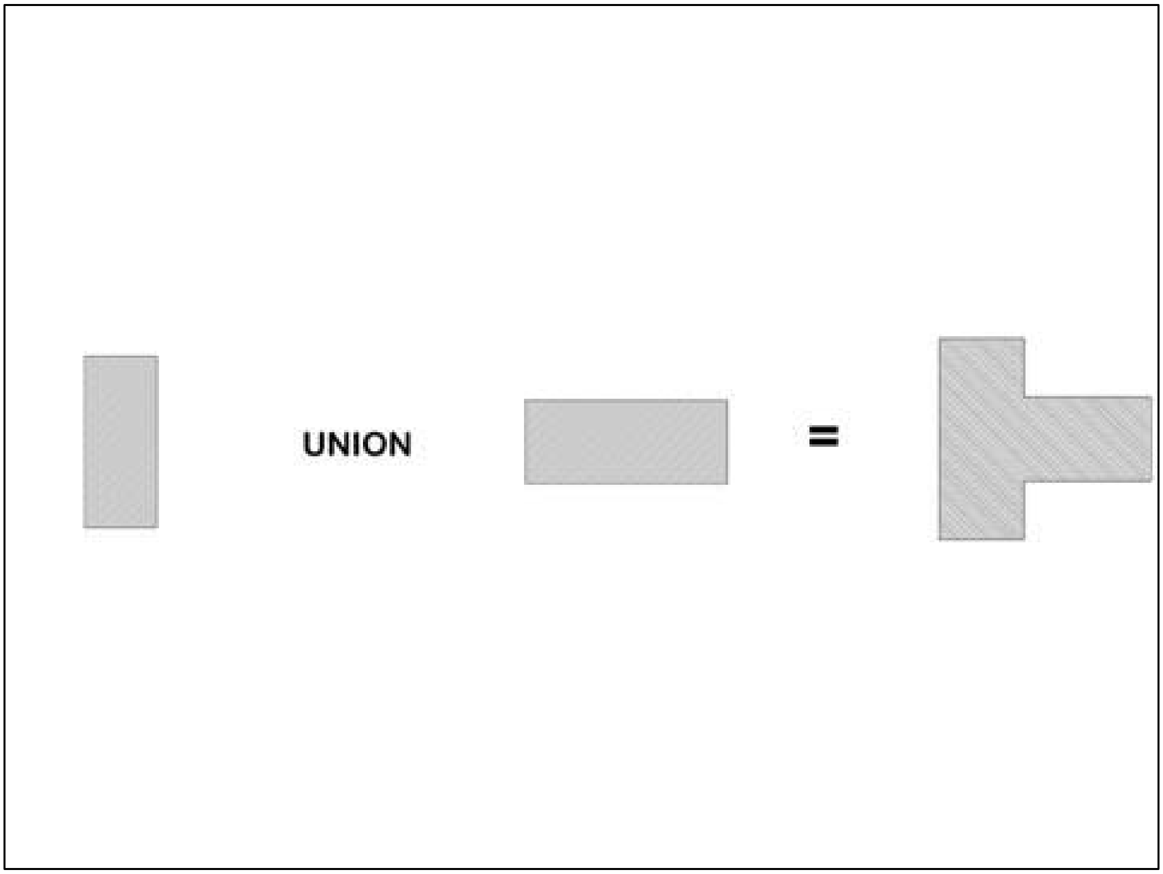

ERASE
=

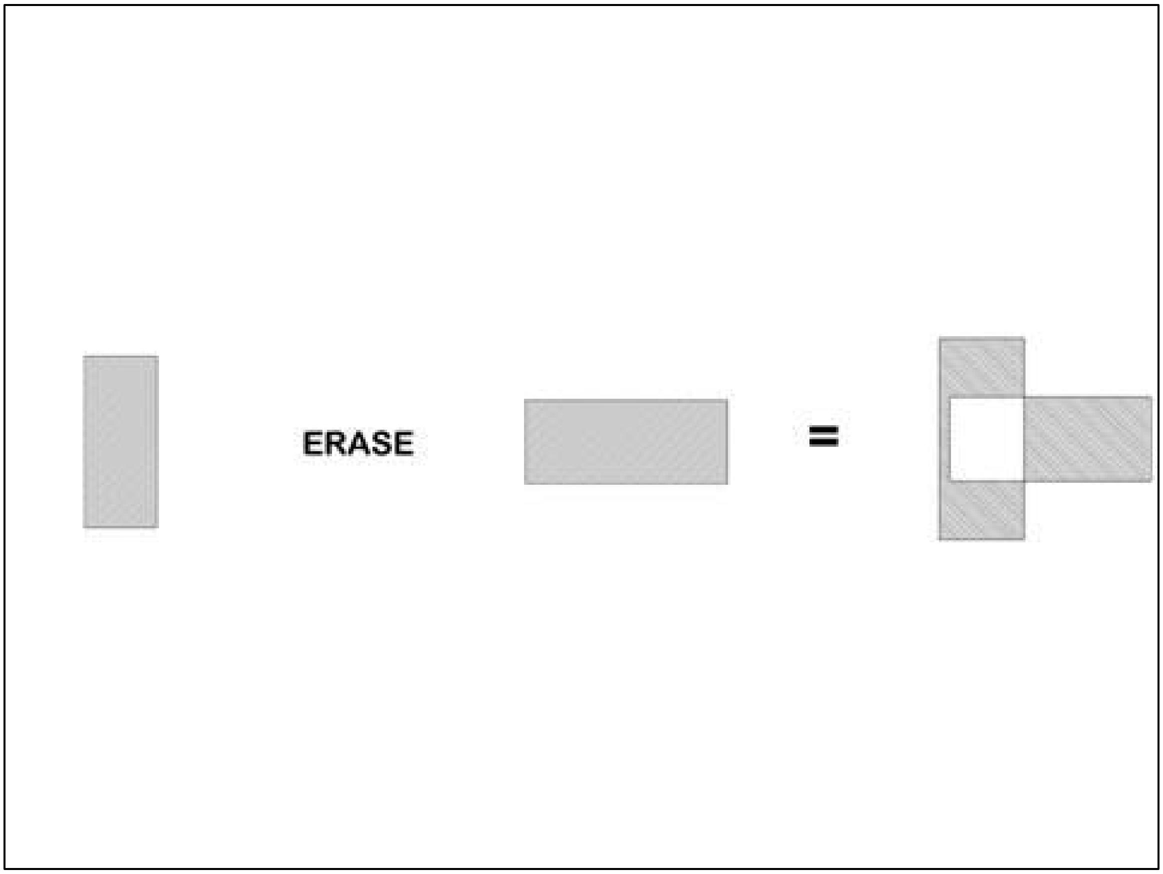

INTERSECT
=

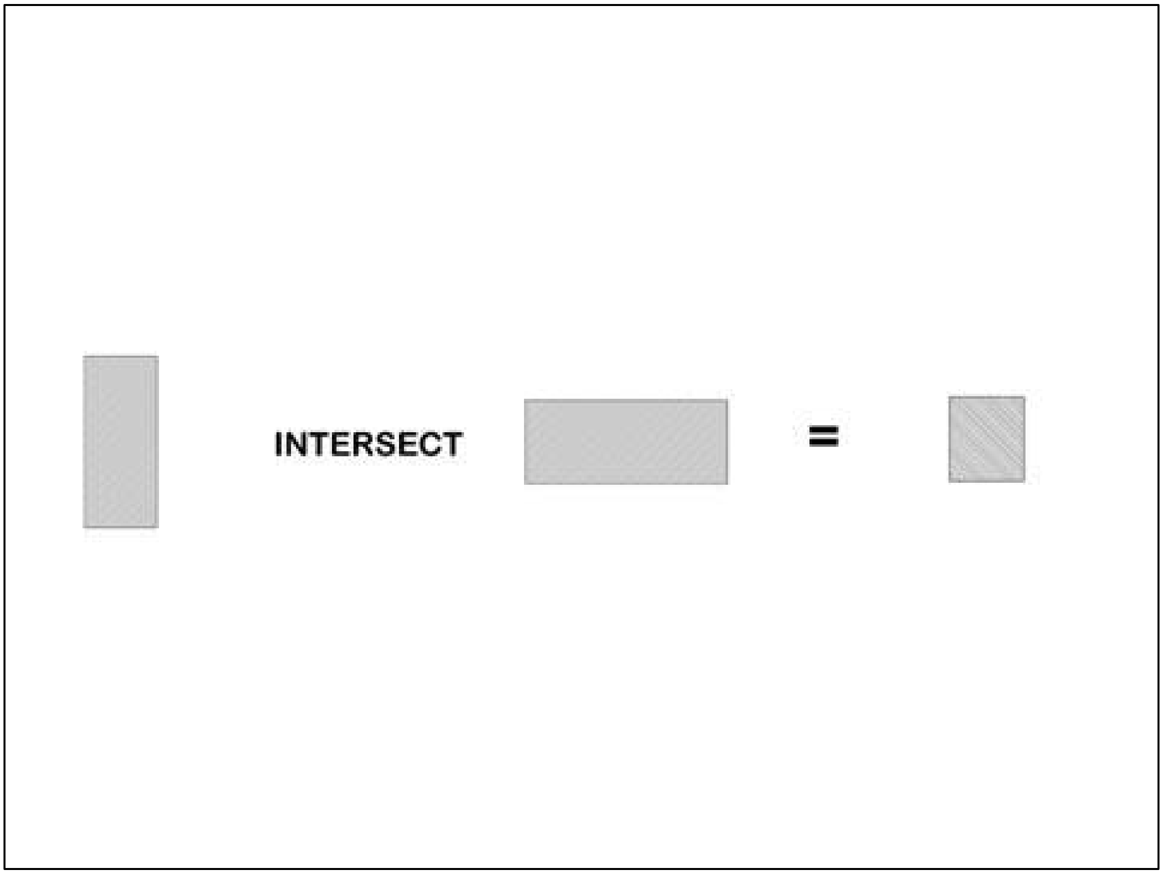

UNION
=

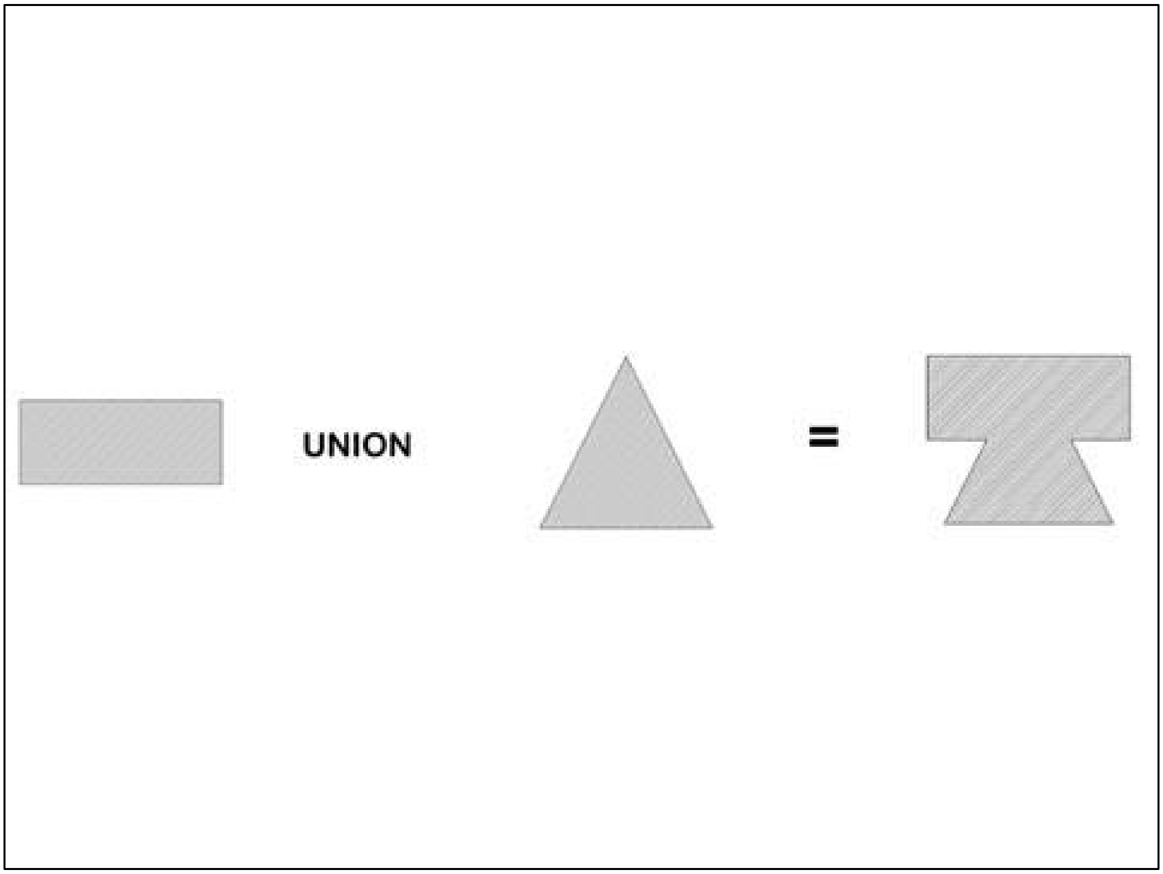

ERASE
=

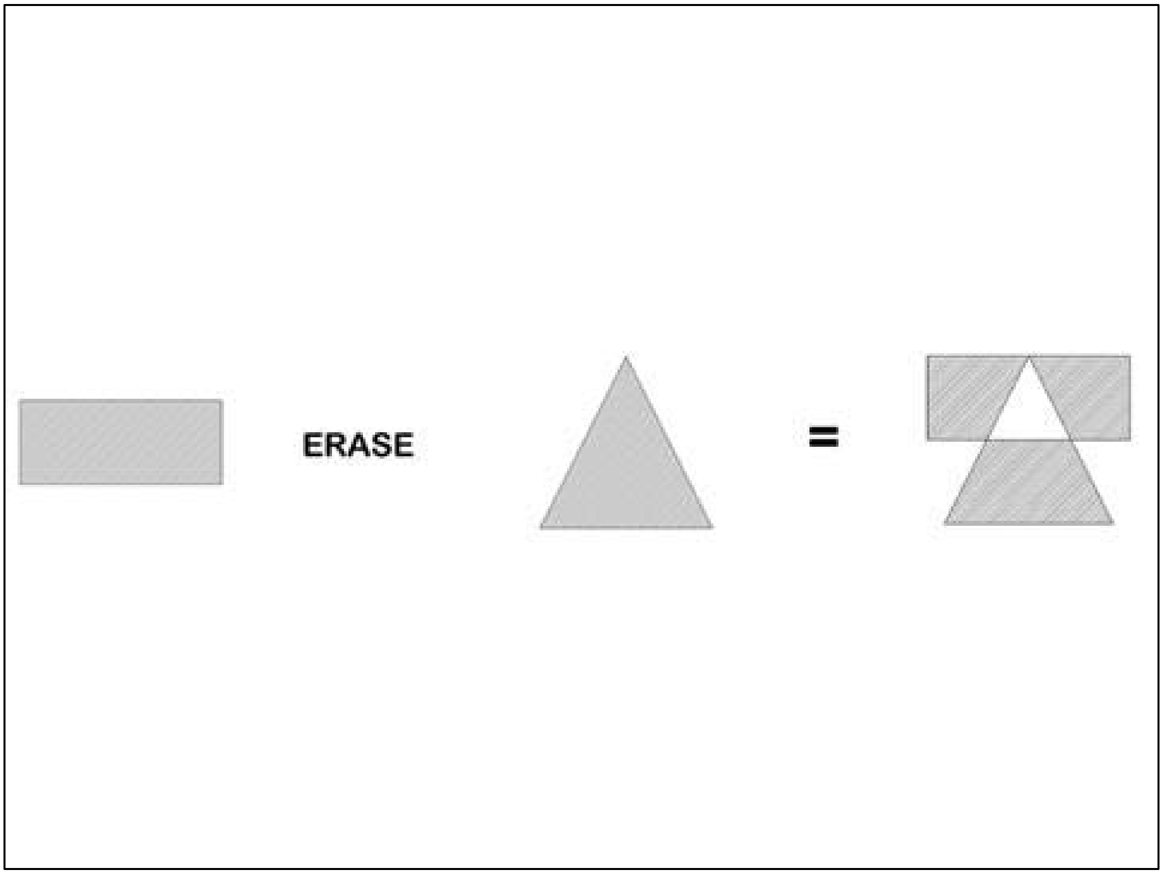

INTERSECT
=

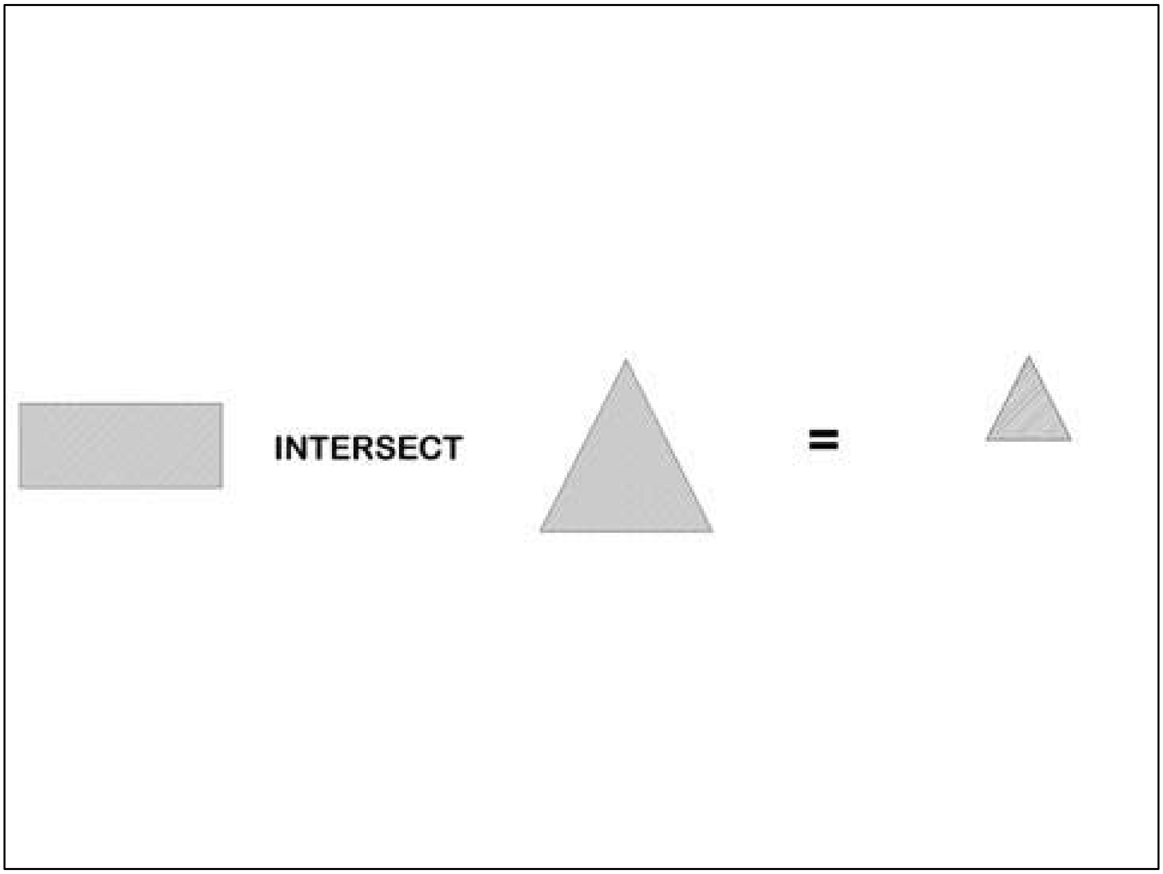

UNION
=


ERASE
=


INTERSECT
=

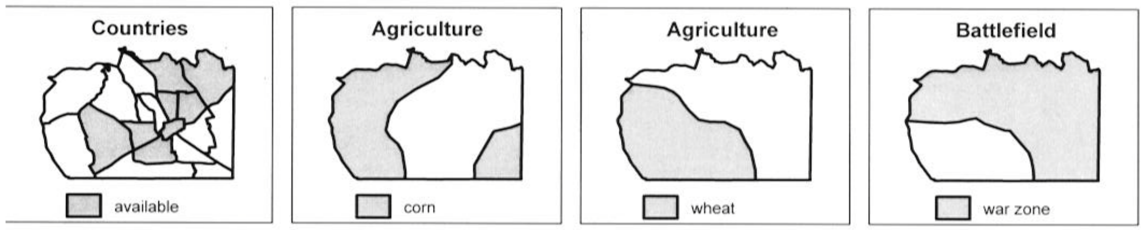

UNION
=


ERASE
=


INTERSECT
=

APPENDIX D.

SITUATIONAL TEST



Use the above figures (4) and the following facts (3) to answer the question.

--Available countries have land available for agricultural purposes.
--Corn and wheat can only grow in designated areas.
--Agricultural crops cannot be grown in war zones.

Which of the following areas represent land where both corn and wheat can be grown and is available for agricultural use?