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Title: A Study of the Relationship Between Perceived Realism and the Ability of Children to Create, Manipulate and Utilize Mental Images in Solving Problems

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The purpose of this study was to determine whether a relationship exists between perceived realism of computer graphic images and the ability of children to solve spatially related problems. Experiments were performed using 23 subjects between the ages of 8 and 11 who were enrolled in an elementary summer school program in Novato, California. Two different computer apparatuses were used: computer workstations and a cyberspace system developed by Autodesk, Inc. The workstation treatment incorporated three booklets to instruct the subjects on how to solve five different spatial relationship problems. The cyberspace treatment included two scripts to guide the subjects in solving two different spatial relationship problems.

Four cognitive ability tests were administered to the subjects. The dependent variable (i.e., spatially related

problem solving) was measured with the Differential Aptitude Test. The three other measures (Minnesota Paper Form Board Test, Mental Rotation Test, and the Torrance Test of Creative Thinking) were used to partial out any effects which visualization abilities and the ability to mentally manipulate two-dimensional figures, displacement and transformation of mental images abilities, and creative thinking might have had on spatially related problem solving.

It was concluded that the relationships between perceived realism and spatially related problem solving, and creative thinking and spatially related problem solving are inconclusive at this time, but worthy of further study. Furthermore, the ability to visualize and mentally manipulate two-dimensional figures, and mentally displace and transform three-dimensional objects are predictors of spatially related problem solving abilities. Finally, cyberspace is highly promising and deserves extensive development as an instructional tool.

A Study of the Relationship Between Perceived Realism and the Ability of Children to Create, Manipulate and Utilize Mental Images in Solving Problems.

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CHAPTER 1

INTRODUCTION

This study is concerned with the relationship between perceived realism and the ability of children to create, manipulate, and utilize mental images in solving spatially related problems. "Imagery," also called "mental representation," is a mental process. The relationship of imagery to thought is longstanding. Aristotle, the Fourth Century B.C. Greek philosopher, considered mental images to be the basic elements of thought (Kaufmann, 1979). He believed that imagery was responsible for both the stimulation and inhibition of thought and subsequent actions. Aristotle argued that the mind, through imagery, sometimes appeared as a "seeing person." John Locke, the Seventeenth Century English philosopher, described thinking as merely the automatic movement from point to point along mental paths established through learning (Mayer, 1983). He believed that since each point along that path is a sensory experience, thinking must involve imagery or other sensory experiences.

Imagery seems to promote children's learning and memory performance (Paivio, 1971; Greeson, 1981; and

Kosslyn, 1980, 1983). Imagery also plays a significant role in recognition memory, free recall, and paired association (Paivio, 1971; Tower, 1983). Tower (1983) not only supported the findings of Paivio, Greeson, and Kosslyn but expanded the benefits of imaginal skills to include the facilitation of attention, concentration, memory, organization of thinking, divergent cognitive abilities, and language development.

Imagery appears to enhance and play an important role in the processes involved in many diverse disciplines (Rhoades, 1983; Bartlett, 1921, 1932). Bartlett (1921) studied the function of images in memory and concluded that imagery is linked to changes in cognition. Subjects who showed an inclination toward inventions in cognition appeared to rely heavily upon imagery. Invention, the bringing in of totally new details, is particularly prone to occur in the course of the use of sensory imagery (Bartlett, 1921). The significance of mental imagery and the ability to manipulate mental images has been shown to provide significant practical application in the fields of mathematics, physics, and scientific inquiry (Ghiselli, 1966). Imagery also plays an important role in such disciplines as art, architecture, chemistry, design, engineering, and invention (Kosslyn, 1983). All of these disciplines may be seen as requiring high degrees of imagination. As an example, Albert Einstein imagined himself traveling at the speed of light; he could then look at the light and better understand its composition (Kosslyn, 1983). Einstein stated that, for him, thought consisted of images and that he very rarely thought in words (Wertheimer, 1945). Einstein believed that his particular ability did not lie in mathematical calculation but in visualizing effects, consequences, and possibilities. Einstein further indicated that this visualizing consisted primarily of clear pictures which could be voluntarily reproduced and combined (Holton, 1986). As another example, Nikola Tesla, who pioneered in radio and invented the alternating-current motor, reported that he could invent a product in his head (Kosslyn, 1983). He could then go on to design all the components which would make up his device in his head. He would then assemble these parts mentally to see their interrelationship and how they would actually fit together. Tesla would then set out to test the working of these parts in his head. He would actually start the machine, let it run for weeks or even months, and then at the end of the period would check the design for wear. An imagery feat of this magnitude would seem to be limited to only the truly gifted, but when Einstein was asked if he used imagery to assist him with his experiments, he replied, "Of course, doesn't everyone?" It did not appear as though Einstein perceived the use of imagery as an exclusive capability of the genius. Einstein's amazement at the question leads one to believe that his use of imagery may have been a practiced form of learning and memory performance.

One important factor of imagery in education may be in the development of transformational abilities or the restructuring of a problem situation. Many people use imagery to assist them with accomplishing spatial tasks that may be simplified, or made more efficient, by first using simulation (Kosslyn, 1983). For example, a person could use different ways to go about the task of moving the furniture in the living room into another arrangement. The first technique, trial and error, may be to physically move each piece of furniture to a new location and see how it looks. This process could continue until the choice is made. The second technique could be to use "simulation imagery." According to Kosslyn (1983) simulation imagery involves using mental imagery to imagine each piece of furniture in a new location. If an individual is capable of using this process effectively, it would certainly be more desirable and easier on the back. In situations such as this, and virtually any other situation, mental imagery provides a way of "viewing" familiar items in new combinations to preview how they interact. Simulating a situation mentally provides a way of anticipating analogous physical situations (Kosslyn, 1983).

Transformation has long been held as a factor in problem solving by phenomenologist (e.g., Gestalt) psychologists such as Maier (1930), Kaffka (1935), Lewin

(1936), and Wertheimer (1945). Gestalt theory has proposed that problems are solved through restructuring the problem situation, or transformation.

Transformation of images appears to perform an important role in many aspects of everyday life, but it is in problem solving that creating, manipulating, and utilizing mental images may prove to be of significant value to the teaching and training of children and adults. Both the current and future goals of education appear to include enhancing the processes of problem solving. More transformational activity is needed in solving less familiar problems, and this transformational activity appears to be carried out by mental imagery (Kaufmann, 1983).

One of the common steps used in solving problems is the mental exploration of existing "schema" or "schemata" to find similarities to old problems, those held in short- or long-term memory, which the new problem may contain (Rumelhart, 1981). According to Rumelhart (1981) a schema is a modifiable information structure that represents generic concepts stored in memory. Schemata represents knowledge that is experienced, interrelationships among objects, situations, events, and sequences of events that normally occur. In this sense, schemata are prototypes in memory of frequently experienced situations that individuals use to look back at and interpret instances of related knowledge (Rumelhart, 1981).

It is this retrospective process that may be important to the study of imagery (Poyla, 1957, 1968,; Posner, 1973; Bransford & Stein, 1984; Dominowski, Loftus & Healy, 1986; Richardson, 1969; Rumelhart, 1981). By looking back at the completed solution, and by reconsidering and reexamining the result and the path that led to it, a person can consolidate knowledge and develop the ability to solve problems (Polya, 1957).

The ability to imagine, and then transform those mental images, appears to be important to thinking (Wertheimer, 1945; Piaget and Inhelder, 1967), memory (Bartlett, 1921; Paivio, 1971; Greeson, 1981; Kosslyn, 1980, 1983), spatial and visual abilities (Kosslyn, 1983), transformational abilities (Mayer, 1930; Kaffka, 1935; Lewin, 1936; Wertheimer, 1945; Shepard and Metzler, 1971; Rumelhart, 1981; Kosslyn, 1980, 1983), creativity (McKim, 1980), and problem solving (Wertheimer, 1945; Piaget and Inhelder, 1967; Kaufmann, 1979, 1980, 1985; Kosslyn 1981, 1983; and Rhoades, 1983). Therefore, if children are capable of "looking" at their mental images and using this information to assist in problem solving and other cognitive skills, then what if they could enhance this information for greater elaboration? In fact, what if information were presented in such a way that children could encode (i.e., store) that information so that mental images may be created, manipulated, and utilized to an even greater degree? That is, will the presentation of visual information (i.e. perceived realism of objects) effect a child's ability to create, manipulate, and use mental images to enhance their problem solving abilities?

Significance of The Problem

Schools, more than any other institution, are responsible for the downgrading of visual thinking (Sommer, 1978). Most educators are not only disinterested in visualization but are hostile to it. They regard imagery as childish, primitive, and prelogical. As a result, classes in engineering drawing, industrial and technology education, and the arts, in which spatial thinking still plays an important role, are considered second-rate intellectual activities. The dominant realities in the academic classroom appear to be words and numbers. Pictures, if they are used at all, are for illustrating concepts.

Rather than develop a model of teaching-learning based solely upon speakers and tedious tasks, Sommer believes it would be preferable to improve the quality of education so that students could focus all their mental faculties, pictorial as well as verbal, on their work. It appears from Sommer's views that school curricula, which emphasize classification and categorical thinking, are likely to penalize the "visualizer" and favor the "verbalizer."

Opportunity for visual expression usually ceases early in the primary grades. The cause of this cessation appears to be the educational notion that a human thinks in words alone (Arnheim, 1969). Arnheim states that in our schools reading, writing, and arithmetic are practiced as skills that detach the child from sensory experience. Only in kindergarten and first grade is education based on the cooperation of all the essential powers of the mind, including visualization; thereafter, this natural and sensible procedure is dismissed as an obstacle to training in the proper kind of abstraction. McKim (1980) terms this kind of detachment of children from sensory experience as "visual atrophy." Contemporary education seriously neglects inner imagery in two ways. First, schools fail to make students aware of their inner imagery. Second, they afford little opportunity for students to develop this inner resource. McKim attributes "visual deterioration" in the American educational system to the lack of visual thinking and mental imagery training. The current system of education actively discriminates against students who are competent in spatial ability (Smith, 1964). These beliefs may be summed up best by McKim (1980, p.29): "Any mental ability that is not exercised decays, and visual ability [imagery] is no exception."

Attempts to downgrade all those subjects involving spatial thinking will prevent the fullest realization of the human potential. For example, a deaf child will usually have more problems in school than will a blind child. In many ways, teachers treat all children as if they were blind. With respect to visual imagery, teachers push students to be "blind" (Sommer, 1978).

The task of education should be to produce an environment for learning. This should be an environment in which there is a new relationship between students and their subject matter in which knowledge and skill become objects of interrogation, inquiry, and extrapolation (Glaser, 1984).

The principles of mental imagery appear to extend to many professions. Medical physicians must frequently visualize the relative positions of internal organs and other bodily parts (Finke, 1989). An architect might invent a new design for a building by imagining a novel arrangement of shapes and forms. Lawyers may have to determine whether an eyewitness testimony is based on recall of actual experiences or imagined experiences. Archaeologists often have to reconstruct mentally, ancient structures out of existing pieces. It would appear as though the skilled use of imagery would be of benefit to individuals in almost all professions.

From a practical educational point of view, focusing on problem solving functions may lead to a more comprehensive approach to how knowledge is represented in memory. Kaufmann (1980) believes that imagery makes possible an increased level of cognitive processing. He has argued that due to adaptability of images to aspects of a problem situation, imagery may be useful for constructing search models for assisting in the solution of problems which contain a high degree of novelty and, therefore, may not be solvable through the application of general principles and rules. Once the mind simulates spatial operations and those operations attain a critical degree of computational power, the mind may provide aid in the solution of abstract intellectual problems far removed from the concrete perceptions of everyday life, including some of the most profound and far-reaching achievements of the human mind (Shepard and Cooper, 1986).

Review of the Literature

The importance of the senses has long been known by psychologists, who believe that thinking, learning, memory, and emotion depend on information from the world received through the senses (Hochberg, 1968; Goldstein, 1989). One of these senses is the sense of visual perception. Visual perception can be explained as: light energy enters a person's eyes and then is changed into electrical signals that are carried to the brain in nerve fibers, and these electrical signals cause the experience of "seeing."

Visual perception is controlled by various factors, including color, brightness, contrast, objects, form, size, movement and depth (Vernon, 1937; Kidd & Rivoire, 1966; Goldstein, 1989). The factors individually and interactively appear to provide visual cues which assist an individual with determining the "realism" of objects. Objects can be perceived as two-dimensional or three-dimensional. The primary difference between perceiving a two-dimensional object and a three-dimensional object, appears to be depth cues (Hochberg, 1968). Depth cues focus on identifying information in the retinal image that is correlated with depth in the world (Goldstein, 1989). When depth cues are present, people appear to experience the world in three-dimensions. Depth cues are commonly grouped into four categories; these include oculomoter, pictorial, motion-produced, and binocular disparity. The perceived realism of objects is effected by each of these cues.

Oculomotor cues depend on an individual's ability to sense the position of their eyes and tension of their eye muscles, e.g. kinesthetic sensations (Vernon, 1937). Oculomotor cues include convergence and accommodation. Convergence happens when eye muscles cause the eyes to turn inward. Accommodation is the action of the lens of the eye bulging to focus on an object near to it. For example, if you position your finger at arm's length in front of your eyes then slowly move your finger toward your nose, as your finger moves closer you will feel your eyes looking inward and you will feel the tension increase inside your eyes, this is convergence. As the lens bulges to focus on the finger, this is accommodation. When you move your finger away from your eyes, the eyes will diverge and the lens' will flatten.

Pictorial cues are formed by images which are projected onto the retina of the eye. Pictorial cues include overlapping, size in the field of view, height in the field of view, aerial perspective, familiar size, and linear perspective. Overlapping occurs when object A covers part of object B, then object A is seen as being in front of object B. The overlap pictorial cue indicates the "relative depth" or that one object is closer than another object (Goldstein, 1989). Size in the field of view provides the pictorial cue where objects in the background take up less of your field of view than objects in the foreground (i.e., larger size causes an object to appear closer). Height in the field of view provides the pictorial cue where objects in the background are not only smaller, but also are higher in the scene. Objects that are higher in a field of view are usually seen as being more distant. Aerial perspective causes people to see distant objects less clearly than those in the foreground. This is a result of particles in the air which obstruct vision. The greater the distance to the object the more the clarity is obstructed by the particles. When your pictorial depth cue is influenced by familiarity, this is termed a "familiar size cue." For example, if you are familiar with the U.S. ten-cent and fifty-cent pieces, imagine seeing both of these coins drawn the same size on a page. Knowing that the dime is smaller than the fifty-cent piece, the cue of familiar size would be invoked, and it would appear as though the ten-cent piece was closer to you than the fifty-cent piece. Linear perspective is a depth cue where edges (i.e., lines) that are parallel converge as they get farther away from the eyes. The greater the distance from the eyes, the greater the convergence. This convergence continues until the lines meet at a "vanishing point." Most people have become familiar with this concept by viewing railroad tracks that meet in the distance or vanishing point. Linear perspective is a common method used for representing a depth cue on a two-dimensional surface to create the illusion that the convergence of parallel lines represent three-dimensional objects. It is linear perspective, or variations of it, that allow two-dimensional drawings to be perceived as three-dimensional objects by artists, architects and engineers.

Movement-produced cues provide information about depth as a result of displacement (Goldstein, 1989). Movement-produced cues include motion parallax, deletion and accretion. Motion parallax is the difference in the speed of movement for objects which are close or far away. Deletion and accretion occur when movement which is not perpendicular to an object's surface causes the objects to appear to move relative to one another. Deletion covers up the back object, and accretion uncovers the back object.

According to Goldstein (1989), binocular disparity is the most important depth cue. All of the other depth cues except for convergence of parallel lines (i.e., linear perspective) are monocular depth cues. Monocular depth cues are effective with one eye or both eyes; binocular depth cues require the use of two eyes. Binocular depth cues are based on the anatomical feature of distance between the eyes. This distance causes each eye to see the world from a slightly different position (Goldstein, 1989). Because of this attribute, humans simultaneously see two different views of the world. It is this "two-eyes" or "two-viewpoints" which provides the most important depth cue or three-dimensional perceptions.

Depth cues, whether real or imagined, appear to play an important part in a person's perception of objects. These perceptions in turn appear to influence mental imagery, and imagery abilities appear to aid individuals in spatially related problem solving skills. But whether there is a relationship between the ability of children to create and manipulate mental images of objects, and the perceived realism of those objects, is still unanswered.

To assist with answering this question the following is a review of mental imagery and its apparent relationship to spatially related problem solving. The first discussion is of the theories of mental imagery. The review then focuses on mental imagery and its reported relationship to problem solving. The review then explores four reported factors (i.e., spatial, displacement and transformation, creativity, and memory) of mental imagery, and their relationships to spatially related problem solving.

Imagery Principles and Theories

What mental images are is a matter which commonly divides psychologists. There are those, (e.g., Paivio, 1969, 1979; Finke, 1989; Shepard, 1966, 1967, 1978, 1981; Pinker, 1980; Kosslyn, 1980, 1983; Johnson-Laird, 1983; and Kaufmann, 1979, 1980, 1985) who argue that images are a distinct mental representation (i.e., pictorial representations). Others (e.g., Baylor, 1971; Pylyshyn, 1973; and Palmer, 1975) believe that images are strings of symbols (i.e., propositional representations). Still others (e.g., McKim, 1980; Ashen, 1984) believe that elaborations of mental representation theories are necessary to define mental images.

Images as a Distinct Type of Mental Representation

People may use two different techniques for storing information in memory: imagery encoding and verbal encoding (Paivio, 1969, 1979). Paivio suggested that people have a tendency to use imagery to memorize the names of concrete objects, such as table or horse, but not abstract concepts, such as truth or beauty (Finke, 1989). According to Shepard (1967) and Standing (1973), Paivio's "duel coding hypothesis" provides one explanation that for most people, pictures are much easier to remember than words.

Piaget and Inhelder (1971) view imagery as "internalized imitation." Internalization is developed in both "reproductive" and "anticipatory" images. They propose that before the age of seven or eight, a child is capable of using only reproductive imagery. After this age, anticipatory imagery is developed. It is during this development that individuals gain the ability to perform novel transformations (e.g., transforming one problem situation into a new problem situation or state).

According to Piaget and Inhelder (1971), "reproductive images" are made up of representations of objects and events which are already known to the subject. On the other hand "anticipatory images" are capable of representing events not previously perceived. It is within these two representational systems that Piaget and Inhelder describe transformational processes. Anticipatory images are divided into two phases: (1) reproducing a transformation and (2) novel transformations. Novel transformations, according to Piaget and Inhelder, are further divided into two divisions. The first are "kinetic anticipatory images," where the individual can imagine only the final result of the transformation. The second is transformational imagery, where mental images are developed in different stages of transformation. Both of these transformational processes would appear to be important to the problem solving process. In some instances of problem solving it appears necessary to transform images through a sequence of displacements such as changes in location, and rotations such as changes in position about the X, Y and Z axes of the three-dimensional object (Shepard and Metzler, 1971). While in other problem solving situations it appears that the singular transformation of schemata or prototypes which are in memory may be all that is necessary for individuals to look back at and update instances of related knowledge (Rumelhart, 1981).

Mental imagery is instrumental in retrieving information about the physical properties of objects, or about physical relationships among objects, that were not explicitly encoded at any previous time (Pinker, 1980). This principle of explicit encoding is further explained by Finke (1989) when showing how imagery appears to be helpful for certain mental tasks. Finke states that few people have ever made an explicit physical comparison to determine whether a pineapple is larger than a coconut. Once this relationship is made explicit, imagery may become less useful. The assumption that imagery may become less useful once information is stored or encoded could possibly be the result of verbal encoding taking on a primary role when certain relationships are made explicit. Shepard (1966) has made a strong argument for this explicit encoding principle by posing the following imagery task: how many windows are there in your house? This is information that few people have explicitly learned. In order to determine this figure, it is usually necessary to create a mental image of the house, possibly room-by-room, and then perform the counting operation from memory. Once this information is explicitly encoded into short- or long-term memory, imagery may indeed become less useful since the verbal code (i.e., information) has been stored.

Spatial relationships between parts of an object may be preserved in a mental image (Kossyln, 1973). Experiments by Kosslyn (1980, 1983) explored the spatial relationships between the parts of objects. He found that these parts are preserved as mental images, analogous to a physical object. Kosslyn's objective was to see, under experimental conditions, if it was possible to measure whether subjects used a depicting representation [mental imagery] or a verbal representation to solve certain tasks. Kosslyn determined that the best way to achieve this was by taking chronological measures in mental imagery scanning tasks. Kosslyn hypothesized that if subjects took more time to scan a "long distance" across a mental image than a "short distance," the subjects were using a pictorial representation of the image and not a verbal representation.

Kosslyn (1980, 1983) additionally explored the properties of mental images by testing his subjects' ability to inspect the size and detail of those images. Kosslyn used animals as the target objects and then asked subjects to look for particular features of the animals in their images. Kosslyn had hypothesized that it would take longer to see features on small animals in images than on large animals. He found that when subjects imagined animals that were very small, the details of that animal were obscured by what he called the "grain" of the mental medium. He determined that it was the size of the pictorial representation that affected the inspection time of mental images. Therefore, there appears to be some evidence (e.g., Kosslyn, 1980, 1983) that the mind may depict mental images as pictorial information and humans appear to be capable of exploring that information in two dimensions.

The finding that humans can explore mental images in two dimensions has been supported and expanded by the work of Johnson-Laird (1983). Johnson-Laird states that images correspond to views of models. As a result of either perception or imagination, models represent the perceptible features of the corresponding physical objects (i.e., mental images maintain spatially related or three-dimension details). In imagining a revolving object, the underlying mental model of the object is used to recall a representation of its surfaces, reflections, and so forth. Supporters (e.g., Shepard, 1966, 1967, 1978, 1981; Kosslyn, 1980, 1983; Finke, 1989; Pinker, 1980; and Kaufmann, 1979, 1980, 1985) of the pictorial representational processes of mental imagery state that relational structure of external events is essentially preserved in the corresponding relational structure of their internal representations.

Expansions of mental representation theories of mental imagery have also been proposed by Roger Shepard and Robert Finke. These include the "Psychophysical

Complementarity Theory" proposed by Shepard (1978) and the "Levels of Equivalence Theory" proposed by Finke (1989).

Shepard (1978, 1981) has integrated data from his experiments on mental transformations, shape recognition, and motion to create his theory of mental structures. According to Shepard (1981), an imagined or perceived shape is represented as a set of points with each point embedded in a multidimensional space with its own non-Euclidean geometry (i.e., more than one line can be drawn parallel to another line that contains the given point). According to Shepard, these spaces do not literally correspond to regions within the brain, but they appear to reside in neural networks (i.e., nervous system) whose interconnections mimic the representative geometry of the space. The different spaces are organized into a hierarchy that weights them according to their relative importance in the organism's visual processing. When a point in a space representing the object's shape and orientation is activated, the activation spreads as a wave with decreasing amplitude through the space, activating the surrounding points in proportion to their distance according to the metric implicit in the geometry of that space. Each of these surrounding points represents the results of a possible transformation of the object, so the proximity of two points in a space can be interpreted as representing the ease of mentally transforming one object into another. The more heavily a particular space is weighted, the stronger will be the wave.

Finke (1989) considers the visual system to be composed of a hierarchy of levels of processing, starting with retinal activity and culminating in conceptual knowledge of the objects seen. Finke's theory, which is basically heuristic in nature, proposes that mental images are characterized by comparing their effects on the visual system with those of physical objects. Finke proposes that mental images, once formed, cause visual mechanisms to be activated. He proposes that mental images are the source of visual activation and not the product of it.

Kosslyn (1983) shows how perception plays a role in imagery when describing his proposed four stages of mental imagery. Kosslyn characterizes these stages as: (1) generation, (2) maintenance, (3) transformation, and (4) inspection. According to Kosslyn, these stages together appear to be responsible for the processes of imagery. The first stage includes the generation of images by external and internal perceptions. That is, images may be generated by physically viewing matter, or through other senses (e.g., picturing a hamburger from its aroma) and from other perceptions (e.g., such as fear). The second stage, maintenance, requires that images be maintained, or rehearsed occasionally, so that they will remain in memory. The third stage, transformation, allows images to fit a new problem situation. The fourth stage, inspection, allows an individual to inspect these images to compare their relationships to the world. Kosslyn (1980) sums up his four components in the following way: "One must select what image to form, must hold this image, perhaps must update it as new information comes in or transform it in other ways, and must 'read off' the results" (p.473).

Children rely more on imagery than do adults (Kosslyn, 1980, 1983; Kaufmann, 1979). This may be a result of familiarity verses unfamiliarity. Imagery plays an important role in memory and learning when the problem involved is novel or unfamiliar to the subject. Imagery is very useful in learning new or novel ideas (Kosslyn, 1980, 1983; Kaufmann, 1979, 1980, 1985; Richardson, 1969; and Bartlett, 1932). Throughout their lives, adults accumulate a great deal of information. They synthesize this information into various schemata which define their views of the world. These definitions are also termed "propositionally stored information." These propositions may become so well rehearsed, or coded, that they become an automatic response and do not require the use of imagery to recall. But in the case of young children, almost everything they learn is new and unfamiliar. Because of this unfamiliarity, according to Kosslyn (1980; 1983), children rely heavily on imagery to interpret information and solve problems.

Shepard (1966, 1967), Paivio (1969, 1979), Kosslyn (1980), Pinker & Kosslyn (1983), and Finke (1989) have proposed four points to argue their belief that images are a distinct sort of mental representation. These four points are: (1) the mental processes underlying the experience of a mental image are similar to those underlying the perception of a physical object; (2) an image appears to be an integrated representation of a scene or object from a particular viewpoint; (3) people appear to be capable of controlling images by continuous mental transformations, such as rotations and synthesis; and (4) images appear to represent objects. It appears as though the intermediate states of these transformations correspond to intermediate states of an actual object undergoing the corresponding physical transformation.

Shepard (1966, 1967), Paivio (1969, 1979), Kosslyn (1980), Pinker & Kosslyn (1983), and Finke (1989) provide strong arguments to support their belief that images are mental representations. These arguments are the mental representations school of thought on imagery theory.

Images as Strings of Symbols

As a contrary view, images are strings of symbols that correspond to propositions (Baylor, 1971; Pylyshyn, 1973; and Palmer, 1975). Pylyshyn (1973) argues that mental images differ from pictures in several important respects. One difference is that images tend to be meaningful and well organized whereas pictures can be fragmented and meaningless. Phlyshyn argues that a mental image would never have an arbitrary piece missing, like a corner torn off a photograph. Rather, images are put together in meaningful, organized ways, and they fade in meaningful, organized ways. Although images may depict how physical objects look, there is more to an image than just its "pictorial" characteristics. If images are formed according to one's interpretations of things; the exact form an image takes can be altered if those interpretations change. Therefore, images may not be static and may indeed be dynamic. This axiom that images are dynamic, or constantly changing, supports earlier studies (e.g., Bartlett, 1932) that found that there is a general tendency for all memories to change over time.

Some of the strongest critics of imagery and implicit memory encoding are proponents of propositional theories. Propositional theories are supported by the concept that memory is based on a single, abstract propositional code. Propositional theorists believe that propositions are not verbal or visual. Propositions specify formal relationships among concepts and their associated properties (Pylyshyn, 1973).

Four arguments have commonly been used to support proposition theory. First, mental processes leading to the strings of symbols that correspond to an image are similar to those underlying the perception of an object or picture. Second, similar elements or parts of an object may be referred to by different propositions that make up the description of the object, Third, propositional representation appears to be discrete and digital, but it can represent continuous processes by small successive increments or variables. Fourth, propositions appear to be true or false objects. They also appear to be abstract in that they do not directly correspond to either words or pictures (Baylor, 1971; Pylyshyn, 1973; and Palmer, 1975).

Baylor (1971), Pylyshyn (1973) and Palmer (1975) have provided some support that images may be strings of symbols and not pictorial representations. Still there are additional theories that are considered elaborations of previous image theories. These are termed "elaborative theories." One such theory is Ashen's (1984) image-somatic response-meaning (IMS) elaborative theory of mental representations.

Elaborative Theories of Mental Representations

Ashen (1984) believes other models [theories], or elaborations of mental representation theories, are more appropriate for explaining the features of the imagining process. Ashen's (1984) triple code or IMS (i.e., image-somatic response-meaning) model is based on his belief that imagery is supported by interconnections between images, psychophysiological responses, and meaning generation. Ashen believes that the activated connections generated during this process establish meaning. It therefore follows that each idea is an image-somatic response-meaning or IMS. Ashen defines an image as a centrally aroused sensation. It possesses all the attributes of a sensation, but it is internal at the same time. An image represents the outside world and its objects with a degree of sensory realism which enables humans to interact with the image as if we were interacting within a real world. Images may also represent their own reality, and images can therefore reconstruct the world or change the world. Ashen's definition of somatic responses is that the seeing of an image results in a somatic or neurophysiological change (i.e., upon seeing the image of an apple, one experiences also its color, texture, taste and smell). Ashen's definition of meaning is that every image imparts a definite significance. Through meaning, the organism interprets its relationship with the visual image or with the world.

The difference between these three imagery theories (i.e., mental representationists, propositionists, and elaboration) appears to be that images are either representations of objects or propositions represented by digital strings of symbols or extensions of these basic theories. The distinction and conflict appears to be tied directly to how one conceives that imagery is encoded into memory.

McKim (1980) attempted to resolve the differences between image theories when he proposed that mental imagery information may be stored as a process. Although there appears to be strong evidence that people may depict mental images in pictorial form (e.g., Paivio, 1969, 1979; Shepard, 1966, 1967; Kosslyn, 1980; Pinker & Kosslyn, 1983; Finke, 1989), no conclusion can apparently be drawn at this time. It may be more appropriate to say that mental images are not actually stored as pictorial representations but as an elaborate process of the relationship between experience and electrical signals. That is, the experience of having the image of an object projected onto the retina of the eye causes specific electrical signals to be generated by receptors (i.e., structures designed to pick up energy from the environment and to change this environmental energy into "electricity"). Signals are then transmitted from the receptors toward the brain by neurons (i.e., cells that are specialized for the transmission of electricity in the nervous system). These electrical signals are "processed" in the brain. Subsequent information is sent in the form of an electrical signal to certain areas of the cortex. The person then perceives the object. On the other hand, experiences such as color and motion will result in electrical signals being sent to another areas of the cortex.

Imagery information is apparently encoded into the brain in this same fashion. The imagery storage process may therefore be defined as a cognitive structure which is actively integrated with memory (McKim, 1980). McKim's "process theory" suggests that cognitive structures which define mental images are accurately remembered only when the initial storing process is correctly reactivated. When the internal structure is remembered it may be displayed mentally just as one perceives a picture. Therefore, once the mental picture is displayed in the mind, thinking may be employed to actively create, manipulate, and utilize mental image's for various cognitive functions, including problem solving.

Mental Imagery and Problem Solving

With the aid of an image, a person can take out of its setting something that happened a year ago, reinstate it with much if not all of its distinctiveness unimpaired, combine it with something that happened yesterday, and use them both to help solve a problem with which they are confronted today (Bartlett, 1932). Kaufmann (1980) states that most current imagery studies and research have concerned themselves only with memory and learning. This concentration appears to neglect the possible functions of imagery in more complex problem-solving activities.

From a practical, educational point of view, it is interesting to note that creative problem solving is easily influenced to a significant degree. According to Kaufmann (1980), there is reason to believe that focusing on problem solving functions may lead to a more comprehensive approach to how knowledge is represented in memory. Kaufmann believes that mental imagery makes an increased level of processing in cognition possible. He has argued that due to the adaptability of imagery to various aspects of a problem situation, imagery may be useful for constructing search models. Such models may assist in the solution of problems which contain a high degree of novelty and, therefore, may not be solvable through the application of general principles and rules.

A human problem solver can be described as an information processing system. Newell and Simon (1972) believe that this system is made up of the three components: memories, the problem space, and the methods which transform or encode the information.

Greeno (1977) has categorized three problem types and the processing skills necessary to solve these problems. The first type is "problems of inducing structure." Inducing structure is best described as analogy and extrapolation problems. The second is called "constructive search problems," such as anagrams and jigsaw puzzles. Greeno states that skill in solving anagram problems has been found to be correlated with success in identifying hidden pictures and in analyzing spatial relations. The third type, and most closely related to this study, is "problems of transformation." According to Greeno, transformation problems are made up of an initial situation, a goal, and a set of operations that produce changes in problem situations. It is while these problem types occur that a move or change operator transforms one state into a new state. This sequence of operations continues until the goal is reached.

Two cognitive techniques which are believed to be used to solve problems are heuristics and means-ends analysis. Heuristics employs knowledge which is stored as "rules of thumb" or general plans of actions or strategies to solve problems (Mayer, 1983). Means-ends analysis evaluates the problem for each state (Greeno, 1977). Greeno proposes three cognitive skills needed for means-end analysis. These skills are: involvement of methods of analyzing situations, the use of composite operations, and the knowledge of the relationships between the states and the operators. The first skill, the involvement of methods of analyzing situations, is the individual's ability to identify features of the problem situation. Also, the individual should be able to differentiate between the problem state (i.e., immediate or initial problem state) and the goal state. The second skill is the use of composite operations to assist the individual with using a combination of mental operations. The third skill is the knowledge of the relations between the states and the operators which transform activities. This state provides that the individual should be able to choose an operator which effects transformation that will, in-turn, reduce the difference between the problem state and the goal state. According to Greeno means-end analysis is a major process in solving transformation problems.

Imagery is tied to human consciousness; an image illuminates problem-solving activities. According to Ashen (1981) imagery is a psychical act which must not be confined only to retrieving and interpreting memory information, but it must also be involved in transforming what it encounters.

Translation of problem information to a visual representation may involve assimilation, and integrated visual diagrams may be useful tools in certain types of problem solving. Mayer (1983) suggests that even subtle differences in the way a problem is presented could have vastly different effects on how a subject assimilates the problem and thus on problem-solving performance.

Downing (1987) goes beyond the traditional research of imagery in exploring the relationship of "place-imagery" and the structure of architectural design inquiry. An image is a sensation of form, color, sound, smell, movement or taste which is fixed in the immediate present and gives substance to past experience and future possibilities. It is Downing's contention that imagery is a vital dynamic link to futuristic problem-solving. Imagery may be the bridge which links the utilization of past experience to present and future situations. According to Downing, this bridging is the way designers tend to use imagery.

There are many types of problems for which imagery can provide short cuts to the final solution (Finke, 1989). One of these is to use imagery to simulate physical events. This use of mental imagery to solve problems has been termed "mental simulation" (McKim, 1980; Kosslyn, 1983; and Levine, 1987). Mental simulations can provide insights that might have been overlooked if one considered only formal or analytical methods in solving problems (Finke, 1989). Another way a person can relate a problem to past experience is to form an image. For example, people can solve linear ordering syllogisms by using imagery (Desoto, London, & Handel, 1965).

The relationship between imagery and problem solving has also been investigated outside the United States. According to Harmel (1977), Bejat studied the relationship between imagery and problem solving in Romania in 1972. Bejat's intention was to improve teaching methods used in his country to promote intellectual growth. Bejat studied at the graphic nature of external and internal images. Of primary importance was the role these graphic images play in the processes of problem solving. Bejat made comparisons of graphic and non-graphic presentation techniques and various planned experiences. Bejat concluded that the most important factor in the training effect of problem solving was not whether the graphic procedure was given by the experimenter or built up by the subject, but was the independent activity of seeking the essential traits of the problem. Bejat believed that the subjects established the relationship between graphics and problem solving by their analysis and synthesis of the data offered by both. It was concluded that subjects used graphic images only when they had difficulties in finding a solution by more familiar procedures.

According to Harmel (1977), Kabanova and Meller also develop special training techniques in Soviet schools for creating images. These techniques constitute one part of a general program for learning how to approach and solve academic problems. Students examine the problem, image the elements in their spatial relationship, and supplement the symbols with related concrete images. It is Kabanova and Meller's belief that without this technique, the image will correspond inadequately to the problem, or will be unstable, either of which will have a negative influence on the problem's solution. In experiments by Kabanova and Meller, students developed visualizing techniques for problems of geometry, arithmetic, compass directions, and distance measuring. According to Kabanova and Meller this is a generalized technique which can be transferred. Kabanova and Meller state that the Soviets believe that the development of these generalized techniques are an important condition for the mental development of school children.

The spatial factor in spatially related problem solving is related to the belief that at some point in the perception and interpretation of the physical world, spatial information must be translated, recorded, or transformed into relational structures that preserve properties like shape, size, orientation, direction, and dimensionality (Olson & Bialystok, 1983). This study examines whether perceived realism of objects assists children with recording (i.e., encoding), translating (i.e., displacing), transforming (i.e., manipulating), and utilizing mental images when solving spatially related problems (i.e., problems which require children to create, manipulate, and utilize mental images which preserve spatial information such as shape, size, orientation, direction, and dimensionality).

Spatial and Visual Characteristics

A criticism has been leveled against the research on imagery by Finke (1989). Finke believes that experiments often fail to distinguish between the visual characteristics (i.e., visual field, acuity, color, brightness, and contrast) of an image and its spatial characteristics (i.e., information that is correlated with depth and size in the world). For example, most humans can close their eyes and have a spatial "awareness" of where objects are located within a room (Finke, 1989). Many of the apparent benefits of visual imagery in information retrieval could, therefore, be due to the spatial properties of images and not necessarily to their visual properties (Finke, 1989). People may close their eyes and have spatial awareness of where objects are located in a room without necessarily visualizing how the objects look.

Spatial orientation may be a reasoning ability while visualization may be related to mental imagery (Richardson, 1969). Richardson reported two significant factors of tasks involving spatial manipulations; spatial orientation and visualization. Spatial orientation within tasks refers to whether spatial relations of one pattern are similar to those of another pattern. Visualization refers to mentally manipulating the elements which make up a spatial pattern. Barrat (1953) attributes three factors to spatial manipulations: spatial manipulation which is equivalent to Richardson's spatial orientation, spatial reasoning, and shape recognition which is equivalent to Richardson's visualization.

Work by Roger Shepard and some of his students has shown that transformational processes may be associated with spatial visualization tasks. Images are supported by the same structures that represent spatial information, and images use many of the same spatial operators (Kosslyn, 1980, 1983; Cooper and Shepard, 1973; & Shepard and Metzler, 1971). One of the most impressive aspects of the experiments by Cooper and Shepard (1973) is that the analog (i.e., pictorial representation) transformation process which they believe takes place during imaging has been implicated in a wide variety of spatial visualization tasks. As a result, images seem to be particularly useful in memory representations of spatial information.

Since spatially related problem solving appears to involve the task of mentally manipulating elements which make up mental spatial patterns or objects, this technique could provide a valid assessment of an individual's ability to solve spatial problems. The ability to create, manipulate and utilize spatial models may subsequently enhance mental images of those models, and this process may be related to a child's ability to more effectively use those mental models (i.e., mental images) to solve spatially related problems.

Imagery Displacements and Transformations

There are an infinite number of paths for processing an object from one orientation to another, and a path can be produced by more than one spatial transformation procedure (Parsons, 1987). Parsons describes these transformational procedures as being in three classifications. The first, "rotation by dimensions," is a decomposition procedure producing a sequence of rotations about a different axis (i.e., a principal axis of the object) for each dimension by which they differ in orientation. The second, "spin process," is rotation about an instantaneously changing axis produced by simultaneous rotations about two orthogonal (e.g., perpendicular) axes (i.e., similar to a spinning top). The third, "shortest path," rotation about an axis (unique for each orientation difference) to correct simultaneously for all differences in orientation while absolutely minimizing the degrees of rotation.

Physical transformational procedures, like those described above, appear to be similar if not identical with mental transformation procedures. The information processing used for transformation of mental images appears to take place in three successive stages (Just & Carpenter, 1975 and 1976). The first stage is "search," in which sections of two figures that potentially correspond to each other are located. The second stage, called "transformation and comparison," is the one that is associated with the process of mental rotation. In this stage, the segments that are taken to correspond in two figures are mentally rotated while a sequence of comparisons is congruent. The final stage, "confirmation," is devoted to determining whether other segments of the figures are congruent as a result of the mental rotation.

Following the belief that mental transformation is similar to physical transformation and that transformation is an important part of the mental imagery process, Finke (1989) proposes five major principles of imagery, including his principle of transformational equivalence. These principles are: "implicit encoding," "perceptual equivalence," "spatial equivalence," "transformational equivalence," and "structural equivalence." Finke's principle of transformational equivalence suggests that mental rotation resembles the actual rotation of concrete objects or patterns. He states: "Imagined transformations and physical transformations exhibit corresponding dynamic characteristics and are governed by the same laws of motion." The belief that transformation of mental images may be analogous to the transformation of physical objects has been supported by other studies of rotation (Cooper and Shepard 1973, 1975, 1978), size (Bundesen and Larsen, 1975), and shape and color (Shepard and Feng, 1972; Dixon and Just, 1978; Shepard & Metzler, 1971).

Cooper and Shepard (1973) studied mental rotation to determine the time that subjects take either to prepare for, or to respond to, the rotation of a single alphanumeric character. They concluded that discrimination between standard and reflected versions (i.e., mirrored images) of rotated characters requires a compensating mental rotation.

Shepard and Metzler (1971) designed a spatial visualization task where subjects compared a model with rotated figures to determine sameness. They compared chronometrical (i.e., timed) identification tasks of varying degrees of rotation and found a correlation between position and time. The average rate of rotation was approximately 60 degrees per second. The subjects were able to rotate the objects with little, or no difficulty, in both the picture plane (i.e., as if you rotated a two dimensional picture by placing a pin at its center, holding the pin, and then spinning the picture with the pin acting as the axis of rotation) and depth (i.e., with the axis of rotation being parallel to the depth of the object). Many of the subjects claimed that in order to match the rotation of the test object they would imagine one of the objects rotated into the same position as the other object. In this way, congruence could be determined if both objects were in the same position and then matched.

Displacements and transformations of objects within mental images appears to be similar to physical displacements and transformations (Finke, 1989). Therefore, mental displacement and transformation such as rotations and mirroring may be enhanced by practicing these skills by using analogous visual tasks. By practicing displacement and transformation skills, children may be able to enhance their ability to manipulate mental images used in solving spatially related problems.

Creativity and Mental Imagery

One of the significant factors of developing mental imagery abilities is that mental images appear to have some association with the processes to which is applied the general term "creative thinking" (Lolla, 1973; Paivio, 1971; Richardson, 1969; Parrott & Strongman, 1985; Kaufmann, 1981; Shaw & DeMers, 1986; Greeson, 1981). Although thinking in terms of problem solving may make use of memory images as concrete elements in the process of achieving a solution, mental imagery, which may involve more than remembered images, can sometimes provide an original idea for the solution of a problem.

There appears to be no universally accepted definition of creativity, although E. Paul Torrance's definition has been used extensively. Torrance (1966) defined creativity as:

> A process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions; making guesses or formulating hypotheses about deficiencies; testing and retesting hypotheses and possibly modifying and retesting them; and finally communicating the results (p.8).

According to Shaw and DeMers (1986), mental imagery is heavily implicated in Torrance's definition of creativity. Torrance (1966) also developed a widely used battery of tests which he purports will measure both figural and verbal modes of creative thinking. Torrance's tests are scored on what he believes are five aspects of creativity: fluency, originality, abstractness of titles, elaboration, and resistance to premature closure. Creative individuals are able to hold and transform large amounts of loosely categorized, perhaps incidentally acquired, information (Torrance, 1966). There may even be a type of imagery process that is separate from imagery memory, which serves as a vehicle for transforming information perceived and stored in a primary mode of processing (Shaw, 1981). Imaging, according to Torrance (1966) and Shaw (1981), appears to be more than a primitive process for recall of passively stored information. Imaging appears to be a process of active manipulation of the given information. Therefore, imaging may account for individual differences in the transformation of information in the incubation stage of the creative process (Wallas, 1926).

Shaw and DeMers (1986) examined the relationship between selected measures of imagery and certain qualitative aspects of creative thinking. The subjects of their experiments were fifth and sixth grade students in a program for the academically gifted. The students were tested for creativeness in group sessions using Torrance's Circles, and the Just Suppose tests. Imagery may also be strongly linked to the originality and flexibility aspects of creative thinking. Additionally, according to Shaw and DeMers, imagery has an important place in both the verbal and nonverbal dimensions of the creative process.

When people are given the opportunity to use unconstrained, exploratory mental synthesis, they are capable of making creative discoveries. In Finke and Slayton's (1988) experiments, subjects were never told to use imagery or to try to be creative; however, almost three-fourths of the subjects reported their strategy for doing the tasks was to imagine combining simple geometric forms, lines, numbers, and letters by trial and error to mentally see if anything familiar emerged. According to Finke (1989), these findings suggest that mental imagery can be used to explore creative combinations of parts in order to discover meaningful objects, shapes, or patterns. Therefore, it appears that a mental image, like an actual physical object, can often be interpreted after combinations of parts are assembled. This mental combining or assembly process appears to be important in creative thinking because it can enhance a person's creative abilities in what some (e.g., Torrance, 1966; Shaw & DeMers, 1986; and Finke, 1989) believe results in highly original and sometimes unexpected creative behavior.

Thompson and Klatzky (1978) provided additional evidence that people can mentally fuse separately presented parts of a pattern in order to verify whether or not the synthesized pattern matches one that is presented intact. If parts of an object can be fused together in a mental image, then an image may have certain structural properties in common with actual physical objects. If so, it may then be possible to detect structures in an image that may not have been anticipated at the time the image was formed. The belief that mental images may be synthesized has also been supported in studies which show that structural relationships among parts of complex geometric patterns can be preserved in mental images (Finke, 1989).

Therefore, images may play an important role in the solution of original ideas, and original ideas may be an important factor in performing creative thinking. Subsequently, creative thinking may be a significant factor in spatially related problem solving.

Memory and Mental Imagery

Newell and Simon (1972) describe three kinds of memory: short-term memory, long-term memory, and external memory. Short-term memory is capable of maintaining limited amounts of information for a short period of time. Information is contained as a finite set of symbols which are displaced after approximately ten seconds without rehearsal. Long-term memory is a permanent memory of potentially infinite symbolic structures accumulated throughout a person's lifetime. Long-term memory stores information for later use. External memory consists of the representations of structures found in the environment. External memory can be externally-presented elements such as instructions or plans, or subject-produced elements such as written accounts.

The importance of memory to the understanding of imagery may be implicit when specific stimuli are presented to the learner and then subsequently removed in some order or fashion during a conceptual learning task (Lolla, 1973). Within this context, the learner must be able to mentally label, store, and recall the previously presented stimuli in such a manner that any inferences between the response and any newly presented stimuli can be drawn to ultimately deduce the correct solution to the conceptual task at hand. On these occasions, memory plays an important role in problem solving (Lolla, 1973).

How is information represented in memory, and how is it retrieved? Problem solving appears to be a process in which people search their existing knowledge in response to a problem (Mayer, 1983). Thinking may be a search and retrieval operation from a store of meaningful knowledge. This process has been called "semantic memory" (Mayer, 1983). Reasoning (i.e., thinking) stems from recognition memory and this memory is usually closely tied to perception, and perception is related to imagery. Paivio's (1971) findings indicate that non-verbal images may function as efficient mediators and thus facilitate recognition memory. Paivio also found that objects, or their pictures, are easier to recall than their verbal labels.

Therefore, using imagery to visually rehearse information may improve one's memory for that information. Imagery may facilitate memory not only by helping to retrieve visual information but by helping to retain the information temporarily so that it can be more effectively encoded into memory (Finke, 1989).

Studies of memory, and its described relationship to mental imagery, appear to support the thesis that memory may be involved in the four factors which were reported to be related to the performance of creating and manipulating mental images. Therefore, measuring a child's spatial and visual abilities, displacement and transformation abilities, and creative thinking abilities may account for any relationship which may exist with memory and its interaction with a child's ability to create, manipulate, and utilize mental images.

Based on the literature presented in this review, it is reasonable to propose that visualization ability and the ability to mentally manipulate two-dimensional shapes, displacement and transformation of mental images, and creative thinking may be independent factors which contribute to mental imagery abilities and, subsequently, enhanced imagery abilities may increase the spatially related problem solving abilities of children. It is also proposed that perceived realism of objects may also be a factor in a child's ability to solve spatially related problems.

It is therefore hypothesized that there is a relationship between the ability of children to solve spatially related problems and the following factors: visualization ability and the ability to mentally manipulate two-dimensional shapes, displacement and transformation of mental images, creative thinking, and perceived realism (i.e., treatments).

The mathematical representation of this hypothesis is:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + e$$

Where:

Y = Spatially related problem solving (response);
X_1 = Visualization ability and the ability to mentally manipulate two-dimensional shapes (pridictor);
X_2 = Displacement and transformation (predictor);
X_3 = Creative thinking (predictor); and
X_4 = Perceived realism (predictor).
β = Unknown parameters.
e = Statistical errors (residuals).

CHAPTER 2

METHODOLOGY

Population and Subjects

The population for this study was school children between the ages of 8 and 11 in grades 3 to 5. The subjects were volunteers from the Novato Unified School District, Novato, California. The 26 subjects were voluntarily enrolled in the summer school program offered by the Olive Elementary School. Olive school has seven class levels, kindergarten through grade 6, with a total enrollment for the 1989-90 school year of 424 students. The total enrollment for the 1990 summer school was 112 students. The 1989-90 student population was 88.9 percent white (Caucasian), 3.3 percent Asian, 0.9 percent Pacific Islander, 4.0 percent Hispanic, and 2.8 percent Black (Melindi, 1989).

Of the 26 subjects, 23 completed all tasks. Fourteen male and nine female subjects were randomly assigned to two groups. One group had 11 subjects, and the other group had 12 subjects. The three who did not complete all tasks were male. The subjects were evenly distributed between the two groups by sex (Chi-Square = .188, ndf = 1, $p = .665$) (Table 2-1) and by age ($t = .80$, ndf = 21, $p = .43$) (Table 2-2).

Table 2-1. Number of Subjects by Sexes and Group.

	Workstation Group	Cyberspace Group	Total
Female	5	4	9
Male	6	8	14
Total	11	12	23

Chi-Square = .188, ndf = 1, p = .665

Table 2-2. Ages of Subjects by Group

Age	Workstation Group			Cyberspace Group			N	
	n	%		n	%		n	%
8	1	.09		1	.08		2	.09
9	4	.36		8	.67		12	.52
10	5	.46		2	.17		7	.30
11	1	.09		1	.08		2	.09
N	11	1.00		12	1.00		23	1.00
Mean	9.55			9.27				
S.D.	.82			.78				
Se	.25			.24				
t			.80					
ndf			21					
p			.43					

Treatments

The treatments for this study were controlled with two different computer apparatuses. Both apparatuses were used to create and manipulate various computer graphic representations of objects.

Twelve computer workstations controlled by 80386 processors and operating under MS-DOS were used as the apparatus for the workstation group. The computer workstations were equipped with 14-inch VGA (640 x 480 pixels) color display monitors and two-button mice. The AutoSketch(R) and AutoCAD(R) programs developed by Autodesk, Inc., were used for this treatment. AutoCAD is a computer-aided drafting program which is capable of developing both two-dimensional and three-dimensional vector line drawings. AutoSketch is a computer-aided drawing program which is capable of developing two-dimensional vector line drawings. Both of these programs are command driven; that is, they are operated by using a mouse pointing device to make command selections from either a pull-down menu (i.e., menus of commands which are displayed when selected via the pointing device) or screen menus (i.e., a list of commands displayed on the right side of the screen). Figure 2-1 shows the typical workstation configuration which was used by the workstation treatment group.

The AutoCAD program was modified by the author for the training. The modifications consisted of creating a new prototype drawing (i.e., a preconfigured drawing which is automatically loaded upon startup of the program) which was configured with two viewports. The two viewports divided the one display screen into two different display "windows." The display windows or viewports were positioned side-by-side. One of the viewports contained the example cube model and instructions, and the other viewport was empty. Additionally, the screen and pull-down menus were customized with commands specifically designed to develop, displace, and transform a replication of the example model.

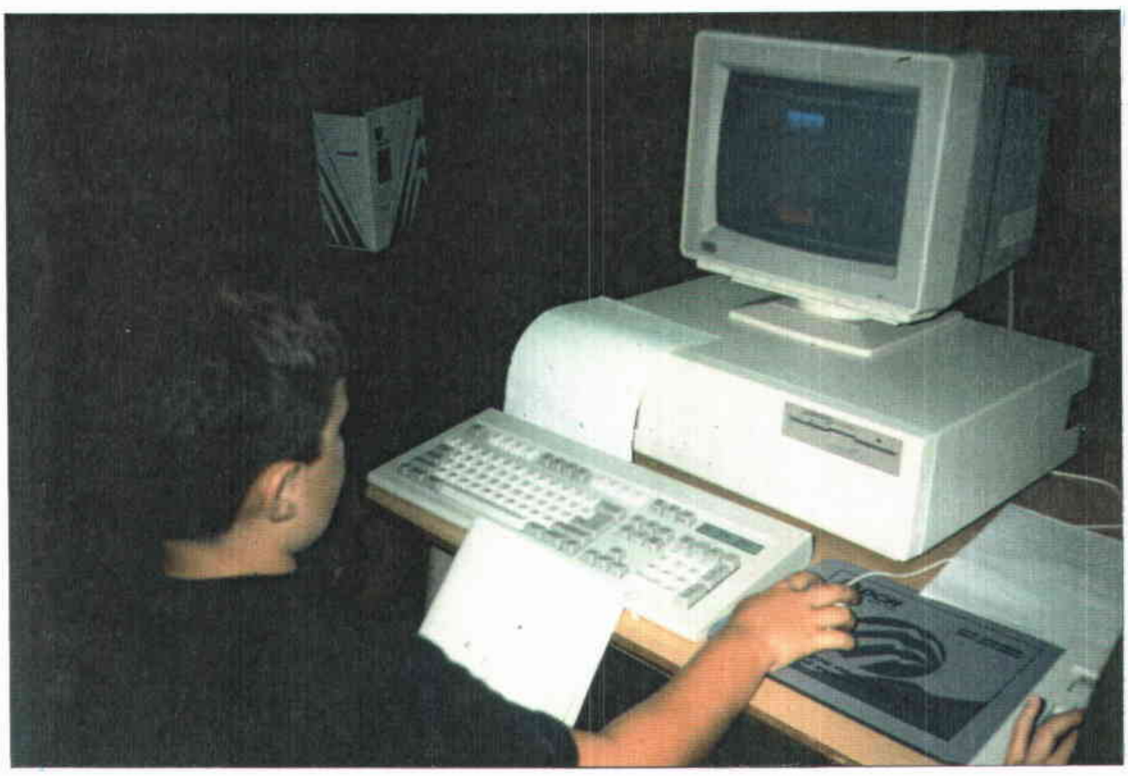


Figure 2-1. A Typical Workstation Used by the Workstation Treatment Group.

The cyberspace treatment was also controlled by a microcomputer which operated using the 80386 processor and MS-DOS. The cyberspace computer system used Matrox SM-1281 realtime graphics boards to generate the necessary computer images.

Input devices included a VPL DataGlove, keyboard, a VPL head-mounted display with two active matrix color LCD televisions and wide-angle optics, and a Polhemus 6-D Isotrak head and hand tracking device. These cyberspace devices are shown in Figure 2-2.

The cyberspace program software was developed by Autodesk, Inc. and is written in C++. The software was designed for sensor tracking, body hierarchy, and dynamics object-oriented for modularity. AutoCAD was used to develop filmroll polygon descriptions of the three-dimensional models, and the Matrox 1281 graphic boards were used to render (i.e., color shade) the models.

Instructions were developed by the author for both treatment groups. The treatment for the workstation group consisted of lectures supported by learning materials in the form of three instruction booklets and computer graphic workstation apparatus. The instruction booklets were used to assist in the training of five different computer graphic tasks (Appendix A).

Figure 2-2. The Cyberspace System Used by the Cyberspace Treatment Group.

The treatment for the cyberspace group consisted of lectures and verbal presentations (i.e., scripts) of the operations which were performed in two different cyberspaces on the cyberspace apparatus (Appendix B).

The treatments were developed, in part, based on Gagne's (1977) "Nine Phases of Learning." The nine stages of "task-cognitive processing" appear to be essential to learning. They are: attending, expectancy, retrieval to working memory, selective perception of stimulus features, semantic encoding, retrieval and responding, reinforcement, cueing retrieval, and generalizability.

Using these "nine phases of learning" as a model, the treatment activities were developed in an attempt to enhance the spatially related problem solving abilities of the subjects. The following section describes how the treatment activities were developed using the "nine phases of learning" as a model.

"Attending" alerts the learner to the stimulus. Attending was facilitated by providing both treatment groups with an introduction to mental imagery, spatial relations, displacement and transformation, creative thinking, and spatially related problem solving, after the conclusion of pre-testing. The subjects were verbally presented "simple" definitions of each of these cognitive abilities, and a discussion of how each of the five pretests was designed to measure these abilities. This information was delivered with the intention of "setting the stage" for learning.

"Expectancy" orients the learner to the learning goal. The subjects were given verbal instructions informing them of treatment activities and apparatus. The instructions regarding the treatment and apparatus built upon the subjects' existing understanding of the five cognitive abilities.

Each of the five problems used for the workstation treatment were presented in the form of instructional booklets (Appendix A). Each booklet described the problem, the operations to perform the necessary sequence, the goal of the treatment, and how to use the apparatus.

The two problems used for the cyberspace treatment group were presented verbally. Each verbal presentation described the problem, the operations needed to perform the necessary sequence, the goal of the treatment, and how to use the apparatus.

"Retrieval to working memory" provides recall of prerequisite capabilities. Retrieval from working (i.e., long-term) memory of the subjects' existing information regarding the five cognitive skills was completed by discussing orally with the subjects these skills and their relationships to everyday life (i.e., mentally moving furniture into new arrangements, instead of physically moving them).

"Selective perception of stimulus features" permits temporary storage of important stimulus features in working memory. The process of selective perception was completed by having the subjects become accustomed to, and use, the designated apparatus without interruption. Both treatments were preceded by familiarization lessons. The workstation subjects used an instruction booklet (Appendix A) to develop a "happy face," and the cyberspace subjects practiced control gestures with an inactive VPL head-mounted display and DataGlove (Figure 2-2).

"Semantic encoding" transfers stimulus features and related information to long-term memory. In the workstation treatment, instruction booklets (Appendix A) and use of the computer workstations were designed to transfer information into a meaningful framework. In the cyberspace treatment group, scripts (Appendix B) and the interaction with the cyberspace apparatus were designed to transfer information into a meaningful framework.

"Retrieval and responding" returns stored information to an individual's response generator and activates a response. The learner retrieves the treatment information from long-term memory to perform various extended tasks. Subjects in the workstation treatment group used graphics and text to develop a prototype school newspaper, and the cyberspace treatment subjects orally discussed some of the prospective uses of cyberspace in the future (i.e., medical doctors using cyberspace to practice surgery).

"Reinforcement" confirms the learner's expectancy about the learning task. For the workstation treatment group, the instruction booklets (Appendix A) provided the subjects with the correct answer to each problem. For the cyberspace treatment group, the correct answers were given orally. During and following each activity, the subjects were given feedback and reinforcement concerning their achievement of the learning goal by both observation of their performance and the instructor's comments. This reinforcement technique confirmed the subjects' acquisition of the new capabilities.

"Cuing retrieval" (i.e., transfer of learning) provides additional cues for later recall of the capability. The opportunity for practice and review was maximized in the treatments for both groups. After completing each of the exercises in the instruction booklets, the computer workstation subjects were allowed to practice and review the lessons (i.e., computer-aided drawing techniques) to enhance the potential for transfer of learning. After completing the required cyberspace lessons, the cyberspace subjects were given time to explore (i.e., practice and review) the three-dimensional cyberspaces without specific instructions.

"Generalizability" enhances transfer of learning to new situations. The treatments should have enabled the subjects to acquire additional cues for retrieval and generalizing spatial relations abilities, displacement and transformation abilities, and creative thinking abilities, and subsequently, spatially related problem solving abilities. Posttests were administered following the treatments to determine whether transfer of learning, and potential generalizability, had occurred.

Workstation Treatment

Five problems for the workstation treatment group were developed in three different instruction booklets (Appendix A). Each booklet contained the instructions describing the problem, the operations to perform the necessary sequence to solve the problem, the goal of the project, and how to use the apparatus. Subjects used the AutoSketch program to develop and manipulate two-dimensional drawings. A modified AutoCAD program was used to develop, displace, and transform a representation of a three-dimensional cube model on a two-dimensional display device.

The first booklet contained two parts: an introduction to the AutoSketch program and a figural completion task (based in part on E. Paul Torrances' Thinking Creatively With Pictures Test, 1990). The second booklet also contained two parts: a two-dimensional puzzle building task (based in part on the Revised Minnesota Paper Form Board Test by Likert and Quasha, 1979), and pattern development and construction (based in part on the <u>Differential Aptitude Test</u> by Bennett, Seashore, and Wesman, 1972).

After completing the previous lessons using the AutoSketch program, the subjects were trained in the development, displacement and transformation of a three-dimensional cube model (based in part on the <u>Rotation Test</u> by Vandenberg, 1971) on a two-dimensional display device. Once the subjects were familiar with the apparatus and modified AutoCAD program, they were instructed to display and examine an example of the experimental target model. The subjects were then instructed to duplicate the target model using the development process as it was presented in the instruction booklet. After the model was developed, the subjects were instructed to displace the model with rotations about the three perpendicular axes (i.e., X,Y, and Z). The model could only be rotated about one of the three axes at a time (no simultaneous axes rotations were allowed) and only in 30 degree increments. After each rotation, the subjects were instructed to visually compare their model against the example model. Additionally, during the rotation process, the subjects were instructed to attempt to mentally rotate the model back to its original alignment to match the example model. The model was then rotated until it was returned to its original alignment.

Once the model was rotated in the three axes, the subjects were instructed to perform a mirroring transformation. Once the mirror model was developed, the original model was deleted. The subjects were then instructed to again displace the model with rotations about the three axes, again at 30 degree increments. After each rotation, the subjects were instructed to attempt to mentally rotate the model to determine whether or not the mirror model would match the example model. The model was rotated until it was returned to its original alignment. After the model was returned to its original alignment, the subjects were instructed to again mirror the model back to its original image and exit the program.

Cyberspace Treatment

"Cyberspace" users interact with three-dimensional models and data as though they are real. This human-computer interface technique provides the ability to virtually simulate any "reality" that can be imagined.

Using a head-mounted display, special positioning sensors, and high speed graphics accelerators combined with software developed by Autodesk, Inc., cyberspace subjects were immersed in a computer-generated three-dimensional world directly under their own control. Subjects could "fly" through cyberspace in any direction and orientation, while simultaneously being able to turn their heads and have the view properly presented in the head-mounted display. Using a DataGlove, the subjects in cyberspace could give commands to the system using various gestures.

The instructions for the cyberspace group were developed in the form of a script (Appendix B) to insure similar presentation to each subject. The instructions described the problem, the operations to perform the necessary sequence to solve the problem, the goal of the project, and how to use the apparatus.

Subjects began the treatment sessions by being introduced to the use and operations of the cyberspace hardware and software by viewing ten 35mm slides of the cyberspace equipment and models. The subjects were then trained in the techniques and gestures which could be used for traveling in, displacing, transforming, and interacting with three-dimensional virtual models by practicing with an inactive DataGlove and head-mounted display. Each subject in the cyberspace group wore the DataGlove and head-mounted display. With this inactive equipment on, the subject was instructed to perform various practice maneuvers; these were making a fist for calibration, moving by directional pointing, stopping movement by opening their hand, moving their head to see in various directions, making a fist to grasp an object, and opening the fist to release the object.

The day after making the practice runs, the subjects wore the active cyberspace equipment. The DataGlove was placed on the subject's hand, and the system was calibrated to each of the individuals hand size and gestures. After the DataGlove was calibrated, the head-mount display was placed on the subjects. Then with the proper gesture (i.e., making a fist with the palm down), cyberspace was activated, and the subject could view the three-dimensional cyberspace in the head-mounted display.

Subjects initially explored cyberspace by traveling in the "office-like" three-dimensional space shown in Figure 2-3. The objective of the first cyberspace experience was to familiarize the subjects with interacting with cyberspace models, and traveling in cyberspace. The office model contained walls, a floor, a beam roof, doors, shelves, bookcases, books, paintings, and a chair. Each subject entered cyberspace, and their first instruction was to turn their head to see the various parts of the office. The starting cyberspace location was directly adjacent to the office.

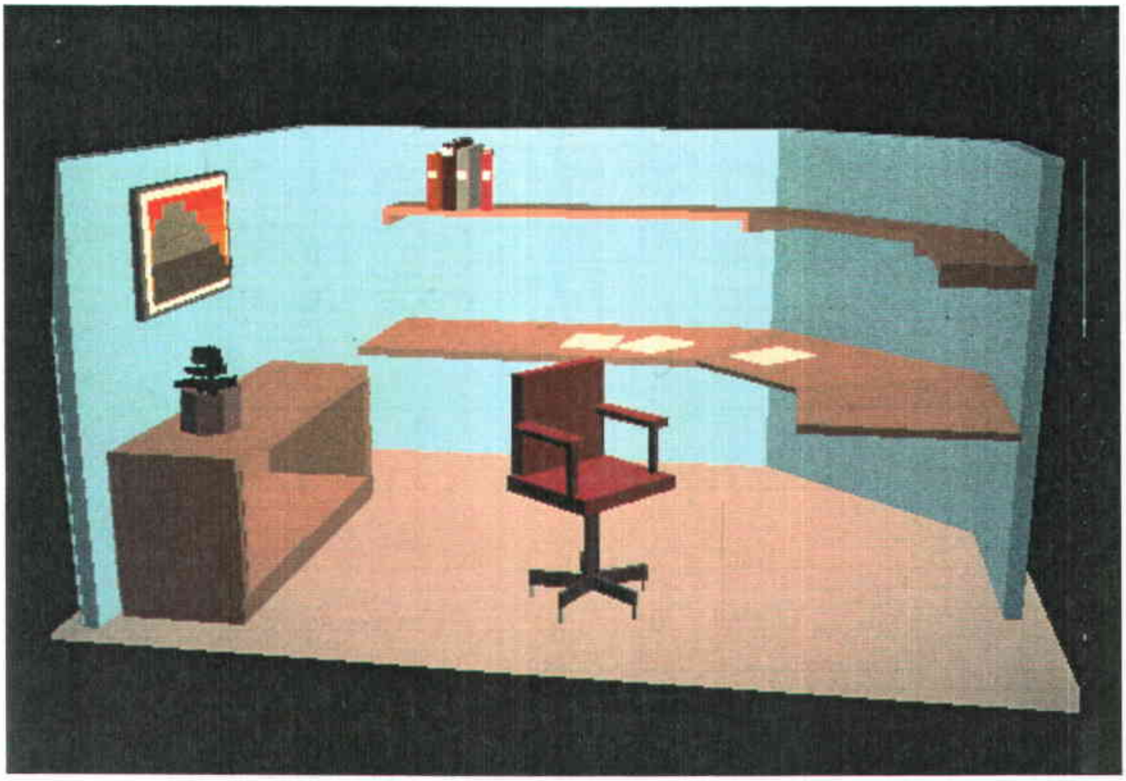


Figure 2-3. The "Office-Like" Three-Dimensional Cyberspace.

The cyberspace treatment required the subjects to travel to, move within, and move outside the office model for a time period lasting 20 minutes, plus or minus five minutes. After completing the traveling, the subjects were then instructed to move to the office chair. When the chair was located, the subject moved close to it, and then grasped the chair. The subjects were then instructed to raise the chair and toss it. This process of traveling to, moving within, and interacting with cyberspace models continued with specified elaborations (see Appendix B).

This same cyberspace contained a "door" into a new space. This space was a "racquetball" court. After the subjects performed the prescribed set of operations in the office space, they were allowed to travel into the racquetball court which contained four virtual objects. These objects were: two balls, a teapot, and a racquet. The subjects were made aware that only the balls and teapot could be grasped by the subject and "thrown." They were then instructed to grasp either the teapot or one of the two balls. This completed the first cyberspace treatment.

The second cyberspace experiment was performed 24 hours after the first treatment. The second cyberspace treatment was designed to have students travel in a large "outdoor" space and find various objects including a sphere (ball), a book, a chair, a racquet, and two cube models, similar to a treasure hunt. The outdoor space contained an open "grass" area with mountains on its perimeter and a sky. This space simulated a horizon which acted as an orientation cue so that the subjects were able to determine various directional commands (i.e., up, down, etc.).

Two cube models (i.e., objects made up of multiple 1 x 1 x 1 cubes) were placed in the space to see if the students could differentiate between a target model or an example and its transformed or mirrored model. The subjects' task was to identify which of the two models matched the untransformed target model. The subjects were instructed to "fly" to the cube models and study them. The subjects were additionally instructed to fly around the models to see them from different viewpoints before making their choice. The default starting cyberspace location was adjacent to a "post" and "slab" structure. The subjects started the treatment by using hand gestures to move toward the structure, and then by flying directly up passed through the slab. Once they were through the slab, they were instructed to look around and locate the required objects. Upon locating each of the required objects, the subjects were instructed to fly toward that object and, as soon as possible, positively identify it. This completed the second cyberspace treatment.

Instrumentation

Five cognitive ability tests were administered to the subjects prior to treatment (i.e., pretest), and ten days after the treatment (i.e., posttest) by treatment groups. Three of the tests were used to measure the subjects' visual imagery abilities and ability to mentally manipulate two-dimensional objects, displacement and transformation abilities, and creative thinking abilities--independent variables. The fourth test was used to measure the subject's spatially related problem solving abilities--dependent variable. A fifth test, The Gordon Test of Visual Imagery Control (Gordon, 1948) was administered, but the data were not used in this study.

Spatially related problem solving abilities were estimated by administering the Differential Aptitude Test: Space Relations Form T (DAT) (Bennett, Seashore, and Wesman, 1972). The DAT test manual reports that successful completion of the spatial relations problems relies heavily on the ability to "visualize" in three-dimensions. The test measures an individual's ability to visualize a finished, solid object from a picture of a flat pattern. According to authors, this ability (i.e., solving problems using the sense of shapes and positions of objects in space) is needed in such fields as architecture, art, and design and by such professionals as dentists, engineers and surgeons.

Reliability coefficients for ninth-grade boys were reported in the test manual as .93 and for ninth-grade girls as .92. The standard error of these coefficients was reported as 3.1 for both ninth-grade boys and girls.

Displacement and transformation abilities were estimated by administering the Mental Rotation Test which was adapted by Vandenberg (1978) from the work of Shepard and Metzler (1971). The Mental Rotation Test is a paper and pencil test of spatial visualization of the displacement (i.e., rotation) and transformation (i.e., mirroring) of three-dimensional block figures. The test contains 20 items in five sets of four items each. Each item consists of a criterion figure, two correct alternatives, and two incorrect ones. Correct alternatives were always identical to the criterion in structure but are shown in rotated positions. One-half of the incorrect alternative items on the test are rotated mirror images of the criterion. There were four untimed examples included in the instructions. The test consisted of two parts, ten items per part and five items per page. Subjects were given three minutes to complete each part. Three scores were recorded: the number of items attempted, the number of incorrect figures in items attempted, and a combination of the above was used for the number of correct figures.

Reliability of the test was estimated by Wilson, DeFries, McClearn, Vandenberg, Johnson, and Richardson

(1975). In a sample of 3,268 adults and adolescents who were age 14 years or older, the Kuder-Richardson Formula 20 coefficient was .88 (Vandengberg, 1978). In a similar sample of 336 subjects, the test-retest correlation was .83 after an interval of one year or more. In a sample corrected for variations in age, test-retest reliability for 456 subjects after one year was .70 (Kuse, 1977).

Creative thinking abilities were estimated with scores on the Thinking Creatively With Pictures: Figural Booklet A (Torrance, 1990). The term "creative thinking abilities," as measured by this test, refers to the constellation of generalized mental abilities that are commonly presumed to be brought into play in creative achievements (Torrance and Ball, 1984). Many educators and psychologists would prefer to call these abilities divergent thinking, productive thinking, inventive thinking, or imagination.

According to Torrance and Ball (1984), several studies have indicated that the reliabilities of the norm-referenced and criterion-referenced measures were above the .90 level. The measures of fluency, originality, and elaboration on the Thinking Creatively With Pictures Test had yielded evidence of test-retest validity as .51 for males and females combined, and .59 for males and .43 for females (Torrance & Wu, 1981).

Visual imagery abilities and the ability to manipulate two-dimensional objects were estimated by administering the Revised Minnesota Paper Form Board Test by Likert and Quasha (1979). This test is a revised version of the original Paper Form Board Test developed in the late 1920's by Paterson, Elliot, Anderson, Toops, and Heidbreder (1930). It is a 20 minute speed test consisting of 64 two-dimensional diagrams cut into separate parts. The subject chooses the one figure which is composed of the exact parts that are shown in the original diagram.

The use of the Revised Minnesota Paper Form Board Test has been reported as a viable test for measuring visual imagery abilities (Paivio, 1971). Additionally, Anastasi (1967) reported that the Revised Minnesota Paper Form Board Test is one of the most valid instruments for measuring the ability to visualize and manipulate objects in two-dimensional space.

Internal consistency for the Revised Minnesota Paper Form Board Test was estimated as .85 by Quasha and Likert (1979). The internal consistency was based on the results of 290 high school seniors applying for admission to New York University. Additionally, Stephens (1945) reported the test-retest reliability of the Revised Minnesota Paper Form Board Test as .85.

To reduce the possibility that the sample violated any assumptions for normality, basic summary statistics (i.e. sample means, standard deviations, Pearson correlations between the variables and naive graphics were explored. The data were investigated through analysis of residual plots (i.e., scatter plots of residuals) and normal probability plots. The model was analyzed with the computer statistics program SPSS PC+ (Norusis/SPSS Inc., 1988).

The means and standard deviations of pretest scores for the two treatment groups and the results of the comparisons of pretest scores by group are presented in Table 2-3.

Table 2-3. Means and Standard Deviations of Pretest Scores by Groups.

	Workstation (N = 11)		Cyberspace (N = 12)
Visualization			
Mean	22.73		17.18
S.D.	7.55		7.91
t		1.03	
ndf		21	
p		.317	
Displacement and Transformation			
Mean	22.09		17.36
S.D.	4.39		5.54
t		2.22	
ndf		21	
p		.038	
Creative Thinking			
Mean	113.00		105.27
S.D.	14.57		19.50
t		1.05	
ndf		21	
p		.305	
Spatially Related Problem Solving			
Mean	28.45		24.64
S.D.	7.78		9.58
t		1.68	
ndf		21	
p		.108	

Their were no significant differences between groups in the areas of visualization (t = 1.03, ndf = 21, p = .317), creative thinking (t = 1.05, ndf = 21, p = .305) and spatially related problem solving (t = 1.68, ndf = 21, p = .108) prior to the treatment. There may be a relationship between groups (i.e., perceived realism) and displacement and transformation abilities (t = 2.22, ndf = 21, p = .038) which may indicate that the workstation subjects may have entered the treatments with better displacement and transformation skills than the cyberspace group.

Comparison of the total groups' pretest mean scores with norms (Table 2-4) indicates that the sample used for this study may not necessarily represent the desired population (i.e., children between the ages of 8 and 11). The sample group may have performed better on the tests than could be expected because of the socioeconomic status of the district, and the "volunteers" may not have represented the population of interest.

Table 2-4. Total Group Mean Scores on Pretests Compared with Test Norms. (N = 23)

	Means	Norms
1. Creative Thinking (Torrance Test of Creative Thinking)	109.14	107.82 (grades 4-6)
2. Visualization (Minnesota Paper Form Board Test)	26.55	40.40 (boys grade 10) 38.50 (girls grade 10)
3. Spatial Related PS (Differential Aptitude Test)	19.95	24.10 (boys grade 8) 23.00 (girls grade 8)

Norms for the same population of interest were available only for the Torrance Test of Creative Thinking (e.g., Torrance, 1990). The Differential Aptitude Test (e.g., Bennett, Seashore, & Wesman, 1974) and the Minnesota Paper Form Board Test (e.g. Likert & Quasha, 1970) provided norms for boys and girls in grades 8 to 10, respectively. The normative data for the Mental Rotation Test (e.g., Vandenberg, 1971b) is presented in a form which were not comparable to the data.

CHAPTER 3

RESULTS AND DISCUSSION

The mean, standard deviations, and standard errors of posttest scores for the two treatment groups are reported in Tables 3-1. The intercorrelation coefficients of the posttest scores are provided in Table 3-2.

Table 3-1. Means and Standard Deviations of Posttest Measures by Group.

	Workstation Group (N = 11)			Cyberspace Group (N = 12)		
	Mean	SD	Se	Mean	SD	Se
1. Spatial Relations	24.73	5.90	1.78	20.73	9.32	2.81
2. Displacement and Transformation	28.18	4.94	1.49	22.46	6.15	1.86
3. Creative Thinking	116.27	8.06	2.43	109.91	13.17	3.97
4. Spatially Related Problem Solving	32.00	5.78	1.74	31.00	10.54	3.18

Table 3-2. Intercorrelation Coefficients among Posttest Factors. (N = 23)

	Factor			
Factor	1	2	3	4
1. Spatially Related Problem Solving				
2. Displacement and Transformation	.5520*			
3. Creative Thinking	.2110	.1790		
4. Perceived Realism (Group)	.2600	.4740*	.2920	
5. Visualizing	.4970*	.2030	.3040*	.0620

(* p < .10)

The primary question of this study was concerned with whether the ability of children to solve spatially related problems was related to perceived realism (i.e., treatment). The variables of visualization, displacement and transformation, and creative thinking were included in the model to partial out any effects which they may have had on perceived realism and spatially related problem solving. The model was tested using stepwise regression at a .10 level of confidence to enter a variable and .15 to remove a variable from the equation. Table 3-3 provides a summary of the results of stepwise regression of the four independent variables on spatially related problem solving.

Table 3-3. Summary of the Results of Stepwise Regression. (N = 23)

Source of Variance	SS	ndf	MS	F	p
Regression	598.57	2	299.28	8.05	.0029
Residual	705.79	21	37.15		

Variables Included in the Equation

Variable	B	SE B	Beta	T	p
Displacement and Transformation	.60	.22	.47	2.73	.0133
Visualization	.38	.16	.40	2.33	.0312
Constant	-4.44	6.89	--	.64	.5273

Variables Not Included In Equation

Variable	Beta In	Partial	Min Tol.	T	p
Creative Thinking	5.95	.01	.88	.03	.9745
Perceived Realism (Group)	-.02	.02	.74	-.08	.9381

The results of the regression analysis indicated that the perceived realism (i.e., treatment groups) did not appear to be significantly related with the spatially related problem solving abilities of children ($p = .94$). The results also indicated that both displacement and transformation and visualizing and mentally manipulating two-dimensional objects were significantly related to spatially related problem solving abilities of children ($R = .68$, $F = 8.05$, $ndf = 1,20$, $p = .00$). Creative thinking was not significantly related to spatially related problem solving abilities of children ($p = .97$).

The mathematical representation of these results is:

$$Y = .40X_1 + .47X_2$$

Where:

Y = Spatially related problem solving (response);
X_1 = Visualization ability and the ability to mentally manipulate two-dimensional shapes (pridictor);
X_2 = Displacement and transformation (predictor);

Perceived realism was introduced by this study as a potential factor or predictor of spatially related problem solving ability of children. The results showed that perceived realism may not be a factor in a child's ability to solve spatially related problems. Perceived realism was defined as the difference between the two treatments provided to the treatment groups (i.e., two-dimensional computer workstations and a three-dimensional cyberspace system). The thesis of this study was that the ability to create, manipulate and utilize mental images could be enhanced through specific computer graphic training, and that enhanced mental imagery abilities would enhance the spatially related problem solving abilities of children. It should be noted, however, that while the treatments were sufficient to affect the spatially related problem solving abilities of the children in both groups (F = 7.35, ndf = 1,20, p = .013) (Table 3-4), they were insufficient to cause a differentiation between the two treatments (F = .57, ndf = 1,20, p = .46).

Table 3-4. Summary of Two-Factor Repeated Measure Analysis of Variance for Spatially Related Problem Solving. (N = 23)

Source of Variance	SS	ndf	MS	F	p
Spatially Related Problem Solving	270.02	1	270.02	7.35	.013
Spatially Related Problem Solving X Perceived Realism (Interaction)	21.84	1	21.84	.59	.450
Within subjects	734.64	20	36.73	--	---
Perceived Realism (Groups)	63.84	1	63.84	.57	.458
Within cells	2232.64	20	111.63	--	---

There may be any number of reasons why perceived realism was not related to spatially related problem solving ability. The results of this study could indicate that the ten days of exposure and eight days of treatments may have been too brief for perceived realism (i.e., the difference between the treatments) to cause differential effects upon the subjects' spatially related problem solving abilities. The workstation subjects averaged two hours per day on task and the cyberspace subjects averaged under one hour per day on task. Finally, six treatments were given to the workstation subjects, and two treatments were given to the cyberspace subjects. According to Cronbach (1963), differences between test scores resulting from different courses (i.e., treatments) are usually small when insufficient amounts of time have been expended to insure the effect of the treatment (i.e., positive transfer or learning). After a series of experiments in learning, Gagne and Baker (1950) concluded that positive transfer (i.e., learning) did not take place from training after eight and sixteen trials but did take place after thirty-two training sessions. Gagne and Baker stated that their research showed that a minimum level of learning is required before transfer may be expected to occur. Thus, the number of treatments may have been too few, and the difference in the number of treatments each group received (i.e., six for the workstation group and two for the cyberspace group) may have been too great for the proposed relationship between perceived realism (i.e., treatments) and spatially related problem solving abilities to have developed.

Although perceived realism (i.e., treatment groups) did not appear to be a factor, the mean scores for both of the treatments collectively appeared to improve the subjects' visualization ability, and their displacement and transformation ability.

Both groups made significant gains on posttest scores over pretest scores on visualization (F = 5.21, ndf = 1,20, p = .033), but the treatments again did not appear to effect the scores (F = 2.40, ndf 1,20, p = .137) (Table 3-5).

Table 3-5. Summary of Two-Factor Repeated Measure Analysis of Variance for Visualization. (N = 23)

Source of Variance	SS	ndf	MS	F	p
Visualization	84.57	1	84.57	5.21	.033
Visualization X Perceived Realism (Interaction)	6.57	1	6.57	.40	.532
Within subjects	324.36	20	16.22	--	---
Perceived Realism (Groups)	250.57	1	250.57	2.40	.137
Within cells	2087.82	20	104.39	--	---

The ability to visualize and manipulate objects in two-dimensional space and the ability to displace and transform mental images appear to have significantly influenced subjects' spatially related problem solving abilities. That is, the ability to visualize and manipulate objects in two-dimensional space and the ability to displace and transform mental images of objects were predictors of spatially related problem solving abilities. These findings appear to support the assertions by Shepard and Metzler (1971), Cooper and Shepard (1973), and Kosslyn (1980, 1983) that mental images may be supported by the same structures that represent spatial information, and spatial images may be related to a wide variety of spatial visualization tasks.

Integrating computers into today's classrooms as teaching tools has become commonplace, but it appears that many instructors use computers and computer-based instruction in their classrooms without knowing how they may affect student learning. It is believed that to be an effective learning tool, computers and computer-based instruction will enhance a student's knowledge and also assist in the student's development of cognitive skills. Although there appeared to be some support in the literature that both knowledge and problem solving skills may be enhanced by the use of computers as a learning tool (Pirolli, 1985), there exists a lack of research to support the effect of perceived realism on acquiring this knowledge and subsequent problem solving skills.

This study has shown that providing children with two- and three-dimensional computer graphic training in visualization and mental manipulation of two-dimensional figures and mentally displacing and transforming three-dimensional images of objects directly effects a child's ability to solve spatially related problems. The results of this study have also shown that the abilities of children to visualize and mentally manipulate two-dimensional figures, displace and transform mental images of three-dimensional objects, and solve spatially related problems can be enhanced by specially designed training in the creation, manipulation, and utilization of two-dimensional and three-dimensional computer graphic models using both computer workstations and cyberspace as training devices. The results have additionally shown that selected training in the use of computer graphic software such as AutoCAD(R) and AutoSketch(R), and hardware such as computer workstations and cyberspace, may change the way one creates mental images, manipulates mental images, and then utilizes mental images in the performance of various cognitive tasks such as visualization and mental manipulation of two-dimensional figures, displacement and transformation of mental images of three-dimensional objects, and spatially related problem solving.

Although the relationship between the ability to visualize and manipulate objects in two-dimensional space and spatially related problem solving appears apparent (i.e. both involve visualization abilities), this linkage is not obvious when further examining the tests used in this study to measure these abilities. The ability to visualize and manipulate objects in two-dimensional space was measured using the Minnesota Paper Form Board Test, which presents its test problems in the form of two-dimensional figures. Spatially related problem solving, on the other hand, was measured using the Differential Aptitude Test, which presents the test problems in the form of three-dimensional figures. According to Mayer (1983), translation of problem information to a visual representation may involve assimilation, and integrated visual diagrams may be useful tools in certain types of problem solving. The subjects in this study were capable of translating two-dimensional information into three-dimensional information to assist them with solving spatial problems. Children may use three-dimensional mental images to assist them with processing information needed for the creation, manipulation, and utilization of various skills such as writing. Writing, by its nature, appears to be a two-dimensional task. The belief put forward here is that many two-dimensional tasks, including writing, may be significantly influenced by a child's three-dimensional spatial relations abilities, and vice versa.

Both treatment groups also made significant gains on posttest scores over pretest scores for displacement and transformation (F = 23.24, ndf = 1,20, p = .000) (Table 3-6). Realism was apparently related to displacement and transformation (F = 7.28, ndf = 1,21, p = .01). However, these differences were pre-existing as indicated in the insignificance of interaction (F = .19, ndf = 1,21, p = .67). That is, the two groups differed on the pretest and then gained in ability in parallel.

Table 3-6. Summary of Two-Factor Repeated Measure Analysis of Variance for Displacement and Transformation. (N = 23)

Source of Variance	SS	ndf	MS	F	p
Displacement and Transformation	343.84	1	343.84	23.24	.000
Displacement and Transformation X Perceived Realism (Interaction)	2.75	1	2.75	.19	.671
Within subjects	295.91	20	14.80	--	---
Perceived Realism (Groups)	300.57	1	300.57	7.28	.014
Within cells	859.91	20	41.30	--	---

Training in the displacement and transformation of computer graphic images of objects may be related to a child's ability to displace and transform mental images which may then be related to solving spatially related problems. According to Greeno (1977), transformation problems are made up of an initial situation, a goal, and a set of operations that produce changes in problem situations. While these types of problems occur, a move or change operator transforms one state into a new state. This sequence of operations continues until the goal is reached. The hypothesis for this study was based on the assumption that the displacement and transformation of computer graphic images would not only enhance childrens' abilities of displacement and transformation of mental images but may also emulate the transformational process described by Greeno. The children's mental images could have corresponded adequately to the problem situations, which in-turn, resulted in a positive influence on the problems solutions.

Three tests (i.e., Differential Aptitude Test, Mental Rotation Test, Thinking Creatively With Pictures: Figural Booklet A, and Revised Minnesota Paper Form Board Test) have been shown to be reliable instruments for measuring the abilities (i.e., factors) which were in question in this study. Since all of the instruments have been shown to be stable, and the experiments lasted only ten days, gains should not be expected without interaction. That is, any gains which may be realized from one, or both of the treatments used in this study, could more than likely be attributable to the treatments themselves and not to maturation or other unanticipated but benificial effects produced in experimental situations (Cook, 1967).

Creative thinking does not seem to be a predictor of spatially related problem solving abilities of children (F = 1.67, ndf = 1,20, p = .21) (Table 3-7). Furthermore, the treatments themselves did not seem to effect the creative thinking abilities of the subjects (F = 1.75, ndf = 1,21, p = .20) (Table 3-7).

Table 3-7. Summary of Two-Factor Repeated Measure Analysis of Variance for Creative Thinking. (N = 23)

Source of Variance	SS	ndf	MS	F	p
Creative Thinking	172.02	1	172.02	1.67	.211
Creative Thinking X Perceived Realism (Interaction)	5.11	1	5.11	.05	.826
Within subjects	2058.36	20	102.92	--	---
Perceived Realism (Groups)	546.02	1	546.02	1.75	.201
Within cells	6254.91	20	312.75	--	---

During the original review of the literature, the <u>Torrance Test of Creative Thinking</u> appeared to be a valid instrument for measuring creativity. According to Torrance (1990), the <u>Torrance Test of Creative Thinking</u> is designed to measure fluency, originality, abstractness of titles, elaboration, and resistance to premature closure. Each of these factors has been indicated to be measures of creative thinking (Torrance, 1966). Although creative thinking was linked to problem solving (Shaw & DeMers, 1986), the Torrance Test of Creative Thinking does not appear to account for this factor. No claim was made on the relationship of test results to space relations abilities. Spatial abilities were believed to be a factor in creative thinking based in part on the works of Torrance (1966), Shaw and DeMers (1986) and Finke (1989). Finke (1989) proposed that mental imagery can be used to explore creative combinations of parts in order to discover meaningful objects, shapes, or patterns. This mental combining has been shown to enhance a person's creative abilities in highly original and unexpected creative behavior (Shaw & DeMers, 1986).

This may indicate that spatial ability is either not a factor in creative thinking or the Torrence Test does not measure all factors of creative thinking, including spatial abilities. It is also plausible to speculate that the Torrance Test of Creative Thinking does in fact measure creativity, but spatial relations abilities may be another type of behavior which is different and independent from creative behavior.

Creative thinking may also be time dependent. That is, to effect the creative thinking abilities of children may require more treatments and more treatment time than this study allowed for. It is possible that the treatment length of eight days was an insufficient time to effect the creative thinking processes of the subjects.

Additionally, a relationship between creative thinking and spatially related problem solving may not have occurred because creating, manipulating and utilizing mental images may not be appropriate treatments by themselves for enhancing children's creative thinking abilities. In this experiment, the subjects were never told to use imagery or to try to be creative by imagining combining geometric forms and lines to mentally see if the solutions to the spatial problems emerged. It may have been necessary to instruct the subjects in how they could use creative mental imagery to assist them with enhancing their creative thinking abilities. It may have also been necessary to instruct the subjects in how they could use creative mental imagery to assist them with solving spatially related problems. This lack of specific creativity training may provide a possible cause for the failing of both treatments to increase the subject's creative thinking abilities.

SUMMARY AND IMPLICATIONS

This study was undertaken to determine if there is a relationship between perceived realism (two-dimensional computer displays and three-dimensional cyberspace) and the ability of children to create, manipulate, and utilize mental images for solving spatially related problems. Visual cues may play an important role in a person's perception of objects. Perceptions in-turn influence how humans create mental images, and mental imagery abilities aid in the development of various cognitive skills. But just what mental images really are is still very much in question.

Theories of what mental images actually are have divided psychologists for years. Some individuals (e.g., Shepard, 1966, 1967, 1978, 1981; Paivio, 1969, 1979; Kaufmann, 1979, 1980; Pinker, 1980; Kosslyn, 1980, 1983; Johnson-Laird, 1983; and Finke, 1989) believe that mental images are representations which are analogous to pictorial representations. Others (e.g., Baylor, 1971; Pysyshyn, 1973; and Palmer, 1975) believe that mental images are strings of stored symbols or verbal representations. Still others (e.g., McKim, 1980; Ashen, 1984) argue that mental images are pictorial representations and also that physiological connections play an important role between images and thinking.

Just what mental images really are does not appear to be answerable at this time. Although it would appear appropriate to posit that mental images may not actually be stored as verbal or pictorial representations, but as a process of the association between experience and electrical signals. The imagery process may therefore be defined as a cognitive configuration which is actively integrated with perception and memory.

Although what images actually are may be in question, humans apparently create and use mental images for various cognitive functions. Individuals may be capable of creating, manipulating and utilizing images held within the mind and subsequently using this information to assist them with problem solving. Additionally, various attributes of mental imagery have been reported to play a role in creating, manipulating, and utilizing mental imagery. These include: visualization (Richardson, 1969; Cooper & Shepard, 1973; and Finke, 1989), displacement and transformation of mental images of three-dimensional objects (Shepard & Metzler, 1971; Just & Carpenter, 1975, 1976; Cooper & Shepard, 1973, 1975, 1978; and Finke, 1989), creative thinking (Torrance, 1966; Richardson, 1969; Paivio, 1971; Lolla, 1973; Greeson, 1981; Kaufmann, 1981; Shaw, 1981; Parrott & Strongman, 1985; Shaw & DeMers, 1986; and Finke, 1989) and spatially related problem solving (Kaufmann, 1980; McKim, 1980; Ashen, 1981;

Kosslyn, 1983; Olson & Bialystok, 1983; Downing, 1987; and Levine, 1987).

Twenty-six subjects enrolled in an elementary summer school program in Novato, California were randomly assigned to two different treatment groups. The subjects were between the ages of 8 and 11 and from grades three through five. Two different computer apparatus were used to create and manipulate various computer graphic representations of objects. One group used twelve computer workstations as a part of their treatment, and the other group used one cyberspace system. The AutoSketch(R) program and AutoCAD(R) developed by Autodesk, Inc. were used for the treatments.

The subjects in the workstation group created, manipulated and utilized two-dimensional drawings and developed, displaced, and transformed a three-dimensional cube model on a two-dimensional computer display device. The workstation group used three booklets which instructed the subjects on how to solve five problems.

The other treatment group used a new technology called "cyberspace" to view and manipulate three-dimensional models. The instructions were given orally to the subjects in this group based on a script. The script gave each subject directions and operations which were to be performed in cyberspace. Each subject in the cyberspace treatment group used the cyberspace system for two different learning experiences. These learning experiences occurred one day apart.

Four cognitive ability tests were administered to the subjects prior to the treatment and ten days after the treatment. The dependent variable (i.e., spatially related problem solving), was measured with the Differential Aptitude Test. The three other measures (Minnesota Paper Form Board Test, Mental Rotation Test, and the Torrance Test of Creative Thinking) were used to partial out any effects which visualization abilities and the ability to mentally manipulate two-dimensional figures, displacement and transformation of mental images abilities, and creative thinking abilities might have had on spatially related problem solving in an attempt to isolate the effects of perceived realism.

The results of the study indicated that a relationship between perceived realism and the ability of children to create, manipulate and utilize mental images in solving spatially related problems is unverified at this time. The results also indicated that displacement and transformation and visualizing and mentally manipulating two-dimensional objects were significantly related to spatially related problem solving abilities of children ($R = .68$, $F = 8.05$, $ndf = 1,20$, $p = .00$). Although creative thinking was found not to be significantly related to spatially related problem solving abilities of children, the relationship between spatially related problem solving and creative thinking is still uncertain .

The results also indicated that both groups made significant gains in spatially related problem solving ($F = 7.35$, ndf = 1,21, $p = .013$), visualization ($F = 5.21$, ndf = 1,21, $p = .033$) and displacement and transformation ($F = 23.24$, ndf = 1,21, $p = .000$), however there were no significant gains by either treatment group for creative thinking ($F = 1.75$, ndf = 1,21, $p = .201$). Additionally, there was no apparent difference between treatments for visualization ($F = 2.40$, ndf = 1,21, $p = .137$) and creative thinking ($F = 1.67$, ndf = 1,21, $p = .211$). The workstation group scores were found to be significantly higher than the cyberspace group on displacement and transformation abilities ($F = 23.24$, ndf = 1,21, $p = .000$), but there was no interaction between the groups and time ($F = .19$, ndf = 1,21, $p = .671$). This would indicate that both groups' scores increased in parallel.

Two possible reasons for perceived realism not to have been related to spatially related problem solving in this study may have been treatment length (i.e., eight days) and numbers of treatments (i.e., six treatments for the workstation group and two treatments for the cyberspace group). Creative thinking may not have been found to be related to spatially related problem solving because the Torrance Test of Creative Thinking may not have been a valid instrument for measuring whether a relationship exists between creative thinking and spatially related problem solving. Creative thinking may also not be a factor in spatially realted problem solving abilities as the treatment time may have been too short and the treatments may have been too few. In addition, enhancing imagery abilities may not by itself be a sufficient treatment for enhancing creative thinking abilities.

Implications

A relationship between perceived realism and the ability of children to create, manipulate and utilize mental images in solving spatially related problems is inconclusive at this time. It still appears important to understand children's spatial abilities in terms of their perceived realism of objects, their encoding of spatial information into mental images, and their subsequent use of those images in solving problems.

Combinations of insufficient treatment time, an insufficient number of treatments and an unequal number of treatments received by the workstation group and by the cyberspace group mitigated against the degree of perceived realism being a factor in spatially related problem solving. A number of procedures should be undertaken to examine further the potential relationship between perceived realism and children's cognitive abilities.

First, longer treatment activities and more treatment sessions should be employed. The treatment activities and treatment sessions should be of equal number and length. Furthermore, the training should be expanded to a minimum of thirty days and the interventions should be expanded to six or more activities for both treatment groups.

Second, time-series experiments should be undertaken to more closely examine the effects of the treatments on visualization and mental manipulation of two-dimensional figures, the ability to displace and transform mental images of three-dimensional objects, and spatially related problem solving on children between the ages eight and eleven. A time-series experiment could provide more definitive understanding on the relationship between visualization and spatial abilities in children.

Third, research should be undertaken which applies the treatments from this study to younger, as well as older, students and adults. The results could assist in better theoretical and practical understanding of the factors that may enhance problem solving. These factors could then be presented in materials to assist in the training and retraining of designers and engineers in thinking creatively and more effectively solving problems.

The relationship between spatially related problem solving and creative thinking is also still unclear. Insufficient treatment time and an insufficient number of treatments may have failed to cause an increase in creative thinking abilities and, therefore, a relationship to appear between creative thinking and spatially related problem solving. An investigation should be performed which uses longer treatment activities and more treatment sessions. It is also recommended that this training be expanded to a minimum of thirty days and the activities be expanded to six, or more, for both treatment groups. Additionally, the factors underlying creative thinking and its measurement should be clarified. The Torrance Test of Creative Thinking: Figural Booklet A may not have been a valid measure for studying the relationship between creative thinking and spatially related problem solving. It is unclear whether or not the factors now addressed by the instrument accounts for spatial thinking and perceptions. Additional research should be undertaken to investigate whether creative thinking should include spatial abilities.

Research which further examines spatially related problem solving, visualization, and displacement and transformation skills for the population of this study should consider using more developmentally appropriate tests. The normative data for the Differential Aptitude Test was only available for 8th grade boys and girls and the Revised Minnesota Paper Form Board Test was only available for 10th grade boys and girls. The normative data for the Rotation Test was available in a form that were not comparable to the results of this study.

Research should be undertaken which expands the investigation of the potential relationship between mental imagery and problem solving and mental imagery and creative thinking. Mental imagery is indicated in the literature to have been important in the problem solving process used by Nikola Tesla as well as in the creative thinking abilities of Albert Einstein. This study opens the door wider on whether mental imagery is useful in searching memory for solutions to problems. The mind is capable of simulating spatial operations such as displacement and transformation, which can facilitate creative problem solving, which in-turn can expand the achievements of humankind. Therefore, advanced research on training children and adults to use mental imagery and creative thinking abilities to enhance problem solving should also move forward. One such study should further examine whether the ability to create, manipulate and utilize mental images of two- and/or three-dimensional objects assists individuals in solving problems. Study should be undertaken which interviews people who are generally recognized as being creative. One approach to this type of investigation would be to interview creative people and determine whether mental imagery ability is an important factor in their ability to solve problems or to think creatively.

Finally, spatially related problem solving abilities of children are influenced by training in visualization and mental manipulation of two-dimensional figures and displacement and transformation of mental images of three-dimensional objects. Additionally, the treatments used in this study enhanced children's abilities to visualize and mentally manipulate two-dimensional figures, displace and transform mental images of three-dimensional objects, and solve spatially related problems. Further research regarding computer workstation graphic-based treatments and perceived realism and their relationship to problem solving should be undertaken. Cyberspace and the workstation treatments used in this study enhanced children's abilities to visualize and mentally manipulate two-dimensional figures, displacement and transformation of mental images of three-diemsnional objects, and solving spatially related problems. Advanced research on particular interactions is warrented. Cyberspace is highly promising and deserves extensive development as an instructional tool.

REFERENCES

Anastasi, A. (1967). Psychological Testing. New York: MacMillian.

Arnoult, M.O. (1953). Transfer of pre-differentiation training in simple and multiple shape discrimination. Journal of Experimental Psychology. 45, 401-409.

Ashen, A. (1981). Image Theory: Odysseus and Oedipus Rex - An essay on current image psychology and the literary technique of consciousness. Keynote address presented at the Fifth American Imagery Conference, New York, November, 1981.

Ashen, A. (1984). IMS: The triple code model for imagery and psychophysiology. Journal of Mental Imagery. 8(4), 15-42.

Baker, H.R. & Baker, B.M. (1984). Multivariate Analysis of Variance (MANOVA): A practical guide to its use in scientific decision making. AL: The University of Alabama Press.

Bartlett, F.C. (1932). Remembering. Cambridge: Cambridge University Press.

Bennett, G., Seashore, H., & Wesman, A. (1972). Differential Aptitude Test - Space Relations - Form T. New York: The Psychological Corp.

Bennett, G., Seashore, H., & Wesman, A. (1974). Differential Aptitude Test: Directions for Administration and Norms - Forms S and T. New York: The Psychological Corp.

Benton, A.L. (1983). Three Dimensional Block Construction. NJ: Oxford University Press.

Bransford, J.D. (1979). Human cognition: Learning, understanding, and remembering. Belmont, CA: Wadsworth.

Bricken, W. (1990). Virtual Reality: Directions of Growth. Paper presented at the meeting of the SIGGRAPH Panel.

Brown, F.R. (1954). The effect of an experimental course in geometry on ability to visualize in three dimensions. Unpublished doctoral dissertation, University of Illinois.

Bundesen, C. & Larsen, A. (1975). Visual transformation of size. Journal of Experimental Psychology: Human Perception and Performance. 1, 214-220.

Cook, D.L. (1967). The impact of the Hawthorne effect in experimental designs in educational research. (Project No. 1757). U.S. Department of Health, Education, and Welfare, Washington, DC: Office of Education, Bureau of Research.

Cooper, L.A. & Shepard, R.N. (1973). Chronometric studies of the rotation of mental images. In W.G. Chase, ed., Visual information processing. New York: Academic Press.

Cooper, L.A. & Shepard, R.N. (1975). Mental transformations in the identification of left and right hands. Journal of Experimental Psychology: Human perception and performance. 104, 48-56.

Cooper, L.A. & Shepard, R.N. (1978). Transformations on representations of objects in space. In E.C. Carterette & M.P. Friedman (eds), Handbook of perception (Vol. VIII: Space and object perception). New York: Academic Press.

Cronbach, L.J. (1963). Course Improvement Through Evaluation. Teachers College Record. 64, 672-683.

Davis, R.V. (1979). Minnesota Spatial Relations Test. MN: American Guidance Service.

Davis, E.G. & Swezey, R.W. (1983). Human factors guidelines in computer graphics: A case study. The International Journal of Man-Machine Studies. 18, 113-133.

Desoto, C.B., London, M., and Handel, S. (1965). Social reasoning and spatial paralogic. Journal of Personality and Social Psychology. 2, 513-521.

Dixon, P. & Just, M.A. (1978). Normalization of irrelevant dimensions in stimulus comparisons. Journal of Experimental Psychology: Human Perception and Performance. 4, 36-46.

Downing, F. (1987). Imagery and the Structure of Design Inquiry. Journal of Mental Imagery. 11(1), 61-86.

Farah, M.J.; Peronnet, F.; Gonon, M.A.; and Giard, M.H. (1988). Electrophysiological evidence for a shared representational medium for visual images and visual percepts. Journal of Experimental Psychology: General. 117(3), 248-257.

Fischer, S.S., McGreevey, M., Humphries, J. and Robinett, W. (1986). Virtual environment display system. Paper presented at the ACM Workshop on Interactive 3D Graphics. University of North Carolina, Chapel Hill.

Gagne, E.D. (1987). The cognitive psychology of school learning. Boston: Little, Brown and Company.

Gagne, R. (1977). The conditions of learning (3rd ed.). New York: Holt, Rinehart and Winston.

Gagne, R.M. & Baker, K.E. (1950). Stimulus pre-differention as a factor in transfer of training. Journal of Experimental Psychology, 40, 439-451.

Glaser, R. (1984). Education and Thinking: The role of knowledge. American Psychologist. 39(2), 93-104.

Glushko, R.J. & Cooper, L.A. (1978). Spatial comprehension and comparison process in verification tasks. Cognitive Psychology. 10, 391-421.

Greeson, L.E. (1981). Mental Imagery and Creativity. In Klinger, E. (Ed.), Imagery: Concepts, results, and applications (pp.215-230). 2, New York: Plenum Press.

Guay, R.B. (1976). Perdue Spatial Visualization Tests. Perdue University.

Harber, N.R., Ed. (1968). Contemporary theory and research in visual perception. New York: Holt, Rinehart, and Winston.

Harmel, S.J. (1977). Imagery instructions with water-jug problems. Unpublished doctoral dissertation, University of Colorado at Boulder, 1977.

Hochberg, J. (1968). In the Mind's Eye. In Harber, R.N. (Ed.), Contemporary theory and research in visual perception. Holt, Rinehart and Winston: New York.

Johnson-Laird, P.N. (1983). Mental Models. Cambridge: Cambridge University Press.

Just, M.A. & Carpenter, P.A. (1975). The semantics of locative information in pictures and mental images. British Journal of Psychology. 66, 427-441.

Just, M.A. & Carpenter, P.A. (1976). Eye fixations and cognitive processes. Cognitive Psychology. 8, 441-480.

Kaufmann, Geir (1979). Visual imagery and its relation to problem solving. New York: Columbia University Press.

Kaufmann, Geir (1980). Imagery, language, and cognition: Toward a theory of symbolic activity in human problem-solving. Oslo/Bergen/Tromso: Univerersitetsforlaget.

Kaufmann, Geir (1985). A theory of symbolic representation in problem solving. Journal of Mental Imagery. 9(2), 51-70.

Kearsley, G.P.; Hunter, B. & Seidel, R.J. (1983). Two decades of CBI research: What have we learned? HumRRO Professional Paper. 26, 3-85.

Kidd, A.H. and Rivoire, J.L. (1966). The development of perception of color, space, and movement in children. Kidd, A.H and Rivoire, J.L. (Eds), Perceptual Development in Children. International University Press: New York.

Klein, E.L. (1985). Computer graphics, visual imagery, and spatial thought. New Directions for Child Development. 28, 55-73.

Klinger, E. (Ed.). Imagery: Its many dimensions and application. 2, New York: Plenum Press. (1981).

Kaffka, K. (1935). Principles of Gestalt Psychology. Harcourt, Brace and Company: New York.

Kosslyn, S.M. (1980). Image and Mind. Cambridge, MA: Harvard University Press.

Kosslyn, S.M. (1983). Ghosts in the minds machine: Creating and using images in the brain. New York: Norton.

Kruegar, M. (1982). Artificial Reality. Addison-Wesley.

Kuse, A.R. (1977). Familiar resemblances for cognitive abilities estimated from two test batteries in Hawaii. Unpublished doctoral dissertation, University of Hawaii.

Lawler, R.W. (1985). Computer experience and cognitive development: A child's learning in a computer culture. Chichester, Ellis Horwood.

Lawler, R.W.; DuBoulay, B.; Hughes, M.; and MacLoed, H. (1986). Cognition and Computers: Studies in learning. New York: John Wiley & Sons.

Lewin, K. (1936). Principles of Topological Psychology. Mc-Graw-Hill: New York.

Likert, R. & Quasha, W.H. (1979). Revised Minnesota Paper Form Board Test. New York: The Psychological Corp.

Mandinach, E.B. (1987). The cognitive effects of simulation-modeling software and systems thinking on learning and achievement. Cambridge: Harvard University, Educational Technology Center.

Marks, D.F. (1973). Visual imagery differences in the recall of pictures. British Journal of Psychology. 61, 17-24.

Mayer, R.E. (1983). Thinking, problem solving, Cognition. New York: W.H. Freeman and Company.

McKim, R.H. (1972). Experiences in Visual Thinking. California: Brooks-Cole Publishing Co.

Melindi, R. (1989). Olive Elementary School and the Novato Unified School District. Unpublished document.

Miller, G.A. (1962). Some psychological studies of grammar. American Psychologist. 17, 748-762.

Miller, G. & Johnson-Laird, P.N. (1976). Language and perception. Cambridge: Cambridge University Press.

Moyer, R.S. (1973). Comparing objects in memory:Evidence suggesting an internal psychophysics. Perception & Psychophysics. 13, 180-184.

Neisser, U. (1967). Cognitive Psychology. New York: Appleton-Century-Crofts.

Newman, D. (1990). Opportunities for research on the organizational impact of school computers. Educational Researcher. 19(3), 8-13.

Norusis, M.J./SPSS Inc. (1988). SPSS/PC+ V2.0. SPSS Inc., Chicago: IL.

Olsen, D.R. and Bialystok, E. (1983). Spatial cognition: The structure and development of the mental representation of spatial relations. Hillsdale, NJ: Erlbaum.

Paivio, Allen (1971). Imagery and verbal processes. New York: Holt, Rinehart and Winston.

Papert, S. (1980). Mindstorms: Children, computers and powerful ideas. Brighton: Harvester.

Parnes, S.J. (1967). Creative Behavior Workbook. New York: Charles Scribner's Sons.

Parrott, C.A. and Strongman, K.T., (1985). Utilization of Visual Imagery in Creative Performance. Journal of Mental Imagery. 9(1), 53-63.

Parrott, C.A. (1986). Visual Imagery Training: Stimulating utilization of imaginal processes. Journal of Mental Imagery. 10(1), 47-64.

Parsons, L.M. (1987). Imagined spatial transformation of one's body. Journal of Experimental Psychology: General. 116(2), 172-191.

Paterson, D.G., Elliott, R.M., Anderson, L.D., Toops, H.A. & Heidbreder, E. (1930). Minnesota mechanical ability tests. Minneapolis: University of Minnesota Press.

Piaget, J. and Inhelder, B. (1971). Mental imagery in the child: A study of the development of imaginal representation. New York: Basic Books.

Pinker, S. (1986). Visual Cognition: An Introduction. In Pinker, S. (Ed.). Visual Cognition (pp. 1-63). The MIT Press: Cambridge.

Pinker, S. & Kosslyn S.M. (1983). Theories of Mental Imagery. In Sheikh, A. (Ed.). Imagery: Current theory, research, and applications (pp. 43-71). New York: John Wiley & Sons.

Pirolli, P.L. (1985). Problem solving by analogy and skill acquisition in the domain of programming. PHD Thesis, Carnegie-Mellon University. AAC8601185.

Posner, M.I. (1973). Cognition: An introduction. Glenview, IL: Scott, Forseman.

Polya, G. (1957). How to solve it. Garden City, New York: Doubleday Anchor.

Poyla, G. (1968). Mathematical discovery Vol. II: On understanding, learning and teaching problem solving. New York: Wiley.

Quasha, W.H. & Likert, R. (1937). The Revised Minnesota Paper Form Board Test. Journal of Educational Psychology. 28, 197-204.

Quasha, W.H. & Likert, R. (1970). Revised Minnesota Paper Form Board Test: Manual 1970 edition - Series AA and BB, MSA and MB. The Psychological Corporation.

Rhoades, H.M. (1983). Training Spatial Ability. In Sheikh, A. (Ed.),Imagery: Concepts, results, and applications (pp. 247-255). 2, New York: Plenum Press.

Richardson, A. (1969). Mental Imagery. New York: Springer Publishing Company.

Rogers, Y. (1986). The potential of the visual image at the interface. Current Psychological Research and Review. 2(5), 105-118.

Rumelhart, D.E. (1981). Understanding understanding. La Jolla: University of California, Center for Human Information Processing.

Sekuler, R. & Nash, D. (1972). Speed of size scaling in human vision. Psychonomic Science. 27, 93-94.

Shaw, G.A. and DeMers, S.T., (1986). The Relationship of Imagery to Originality, Flexibility and Fluency in Creative Thinking. Journal of Mental Imagery. 10(1), 65-74.

Shepard, R.N. (1978). The Mental Image. American Psychologist. 33, 125-137.

Shepard, R.N. & Cooper, L.A. (1986). Mental Images and Their Transformations. Cambridge, MA: MIT Press.

Shepard, R.N. & Feng, C. (1972). A chronometric study of mental paper folding. Cognitive Psychology. 3, 228-243.

Shepard, R.N & Metzler, J. (1971). Mental rotation of three-dimensional objects. Science. 171, 701-703.

Shorr, J.E. (1974). Shorr Imagery Test. Los Angeles: Institute for Psycho-Imagination Therapy.

Snow, R.E. (1980). Aptitude processes. In R.E. Snow, P. Federico, and W.E. Montague (eds.). Aptitude, learning, and instruction. 1, 27-63. Hillsdale, NJ: Lawrence Erlbaum Associates.

Sommer, R. (1978). The Mind's Eye. New York: Delacorte Press.

Stafford, R.E. (1962). Identical Blocks, Form AA. University Park, PA: Pennsylvania State University.

Standing, L. (1973). Learning 10,000 pictures. Quarterly Journal of Experimental Psychology. 25, 207-222.

Stephens, E.W. (1945). A comparison of New England norms with national norms on the Revised Minnesota Paper Form Board Test-Series AA. Occupations. 24, 101-104.

Sutherland, I. (1968). A head-mounted three dimensional display. FJCC, 33, pp. 757-764.

Thurstone, L.L. & Jeffrey, T.G. (1959). Space Thinking (flags). Chicago: Education-Industry Service.

Torrance, E.P. (1962). Guiding creative talent. Englewood Cliffs, NJ: Prentice Hall.

Torrance, E.P. (1966). Torrance tests of creative thinking: Norms and technical manual. Princeton, NJ: Personnel Press.

Torrance, E.P. (1972a). Tendency to produce unusual visual perspective as a predictor of creative achievement. Perceptual and Motor Skills.

Torrance, E.P. (1972b). Predictive validity of "bonus" scoring for combinations on repeated figures tests of creative thinking. Journal of Psychology. 81, 167-171.

Torrance, E.P. (1972c). Predictive validity of the Torrance tests of creative thinking. Journal of Creative Behavior. 6, 236-252.

Torrance, E.P. (1972d). Career patterns and peak creative achievements of creative high school students twelve years later. Gifted Child Quarterly. 16, 75-88.

Torrance, E.P. (1974). Torrance tests of creative thinking: Norms and technical manual. Bensenville, IL.: Scholastic Testing Service.

Torrance, E.P. (1980a). Creativity and futurism in education: Retooling. Education. 100, 298-311.

Torrance, E.P. (1980b). Growing up creatively gifted: a 22-year long longitudinal study. Creative Child and Adult Quarterly. 5, 148-158, 170.

Torrance, E.P. (1981a). Predicting the creativity of elementary school children (1958-80) - and the teacher who "made a difference." Gifted Child Quarterly. 25, 55-62.

Torrance, E.P. (1981b). Emperical validation of criterion-referenced indicators of creative ability through a longitudinal study. Creative Child and Adult Quarterly. 6, 136-140.

Torrance, E.P. (1990). Norms Technical Manual: Figural (Streamlined) Forms A & B. Bensenville, IL: Scholastic Testing Service.

Torrance, E.P. & Ball, O.E. (1984). Torrance tests of creative thinking streamlined (revised) manual including norms and directions for administering and scoring figural A and B. Bensenville, IL: Scholastic Testing Service.

Torrance, E.P. (1990). Thinking Creatively With Pictures - Figural Booklet A. Bensenville, IL: Scholastic Testing Service.

Torrance, E.P. & Wu, T.H. (1981). A comparitive longitudinal study of the adult creative achievements of elementary school children identified as highly intelligent and as highly creative. Creative Child and Adult Quarterly. 6, 71-76.

Tower, R.B. (1981). Imagery measurements in Clinical Settings: Matching the Method to the Question. In Klinger, E. (Ed.), Imagery: Concepts, results, and applications (pp. 79-92). 2, New York: Plenum Press.

Tower, R.B. (1983). Imagery: Its Role in Development. In Sheikh, A. (Ed.). Imagery: Current theory, research, and applications (pp. 222-251). New York: John Wiley & Sons.

Vandenberg, S.G. (1971a). A test of three-dimensional spatial visualization. University of Colorado.

Vandenberg, S.G. (1971b). Answer Key and Centiles for the Mental Rotation Test. University of Colorado.

Vandenberg, S.G. & Kuse, A.R. (1978). Mental Rotations, A group test of three-dimensional spatial visualization. Perceptual and Motor Skills. 47, 599-604.

Vernon, M.D. (1937). Visual Perception. The University Press: Cambridge.

Wallas, G. (1926). The art of thought. New York: Harcourt Brace.

Walser, R. (1990a). The emerging technology of cyberspace. (Available from Autodesk, Inc.: Sausalito, CA.)

Walser, R. (1990b). Elements of a cyberspace playhouse. Paper presented at the meeting of the National Computer Graphics Association. Anaheim, CA.

Wertheimer, M. (1945). Productive thinking. New York: Academic Press.

Wilson, J.R.,DeFries, J.C.,McClearn, G.E., Vandenberg, S.G., Johnson, R.C. & Rashad, M.N. (1975). Cognitive abilities: use of family data as a control to asses sex and age differences in two ethnic groups. International Journal of Aging and Human Development. 6, 261-298.

Zukav, A.M.(1979). The Dancing Wu Li Masters: An Overview of the New Physics. New York: Morrow.

APPENDICES

APPENDIX A

Workstation Treatment Instruction Booklets

The Creative Technologies Project

by Mark L. Merickel

in cooperation with
Autodesk, Inc., the Novato School District,
and Oregon State University

AUTOSKETCH®

The Workstation Project
AUTOSKETCH
Figural Completion Task
Instruction Booklet

1

Introduction

The creative technologies project is designed to introduce students to new and exciting ways to use computers. The workstation project introduces students to the processes of developing and manipulating two-dimensional geometric figures. It is believed that this development and interaction with computer graphic models will enhance certain cognitive abilities. Included in these are: spatial and visual abilities, displacement and transformational abilities, creativity, and spatially related problem solving.

To complete this project the participants will use a computer workstation operating under DOS. The participants will be using the AutoSketch (R) program by Autodesk, Inc.

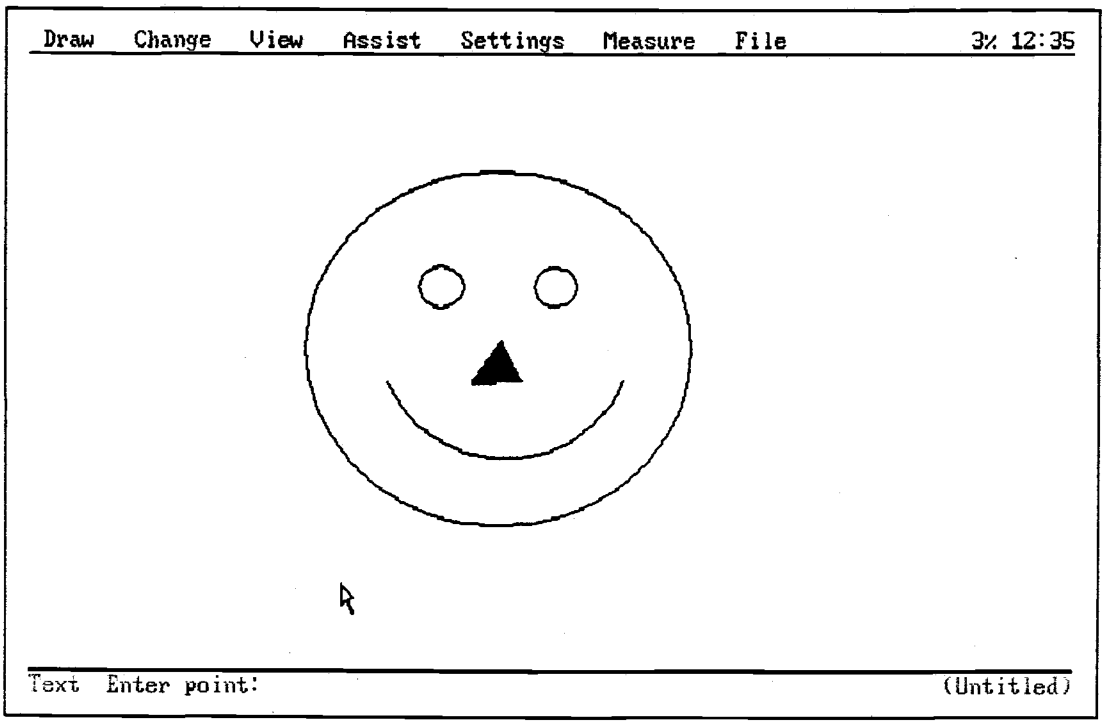
The following pages contain the instructions for the project. Each participant should be seated at a workstation before starting the project. The instructions are designed to be followed, and performed on the workstations, in sequence. If the participant becomes confused at any time throughout the project, it is recommended that the "instructor" assist them with restarting the project from the beginning.

Instructions

The following pages show you how to develop and modify geometric shapes. The model that you develop may not match the example shown in this instruction booklet. That's OK.

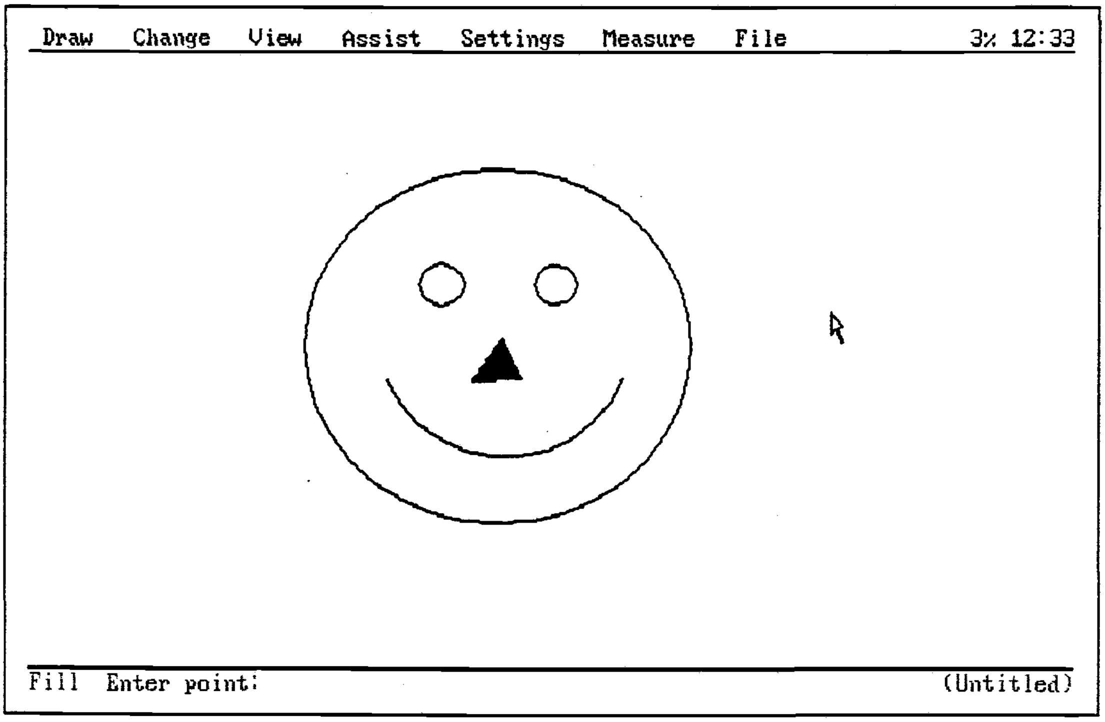
The following pages give you written instructions for each step of the project. The instructions will appear at the bottom of each picture (just like the picture below).

The pictures show you how your screen will look during each step. You should look at the picture first, then read the instructions. After reading the instructions you are to do what the picture shows and the instructions say.



Move the cursor to the point shown.

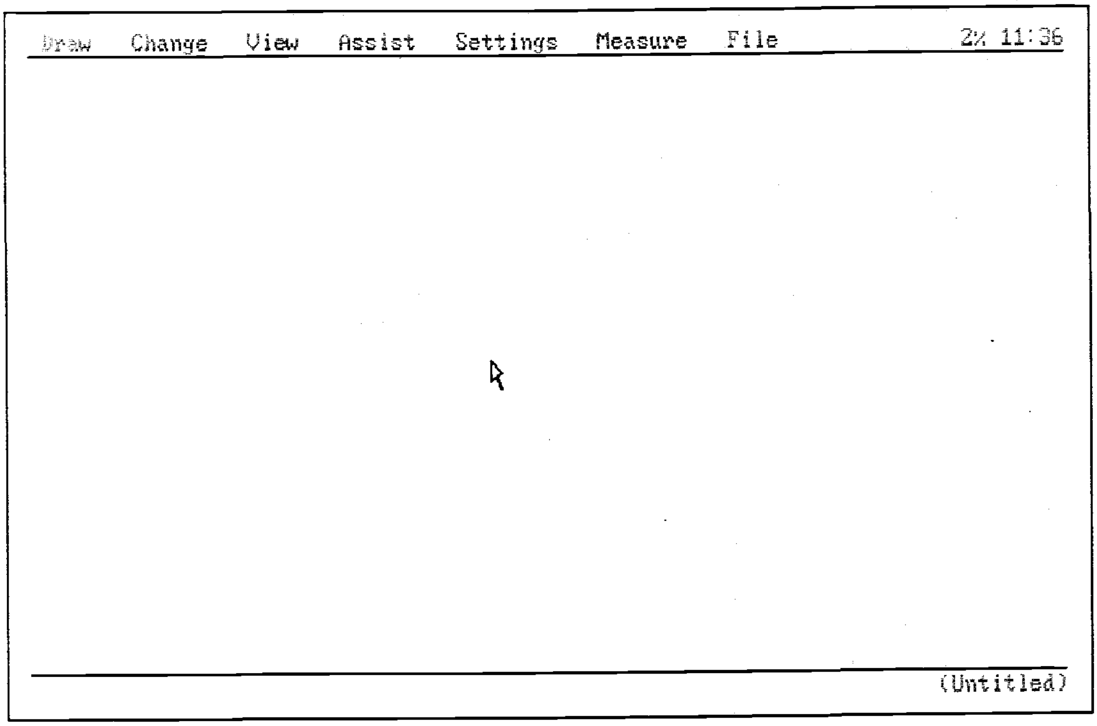
Some of the pictures are examples (just like the one below). These pictures are just to show you the different parts of the computer screen, or, how your drawing should look at that time. These picture pages are marked JUST LOOK AND READ. When you are to do something on the computer, the picture pages are marked DO THIS.



What a happy face.

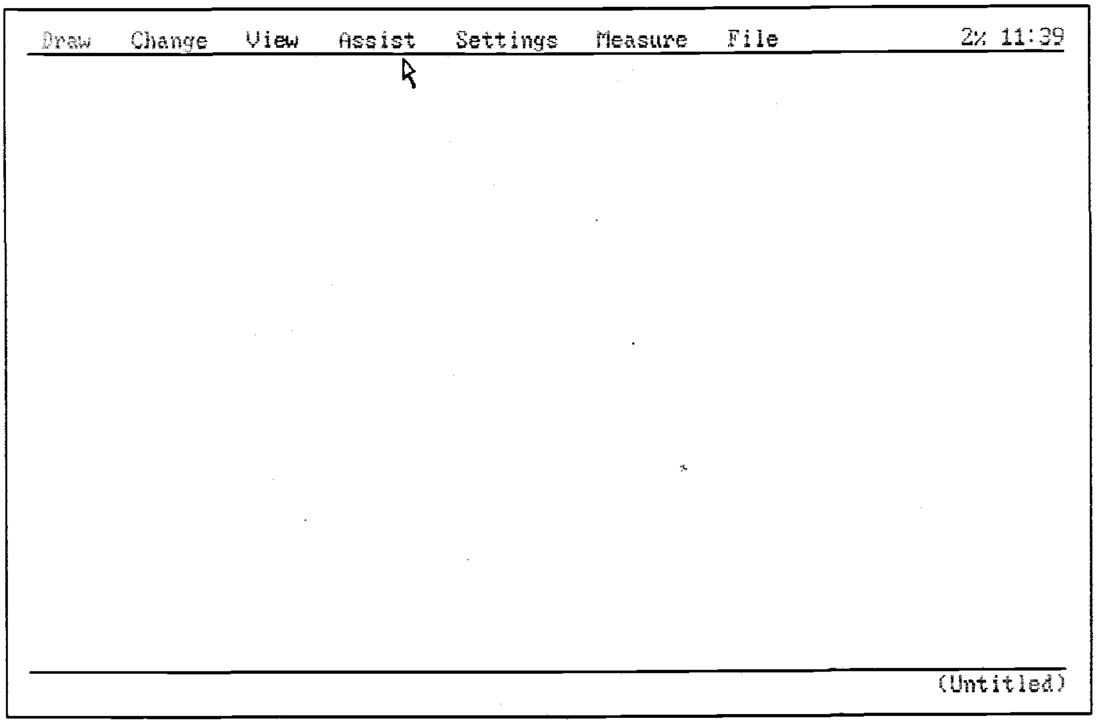
JUST LOOK AND READ

Now turn the page and follow the instructions.



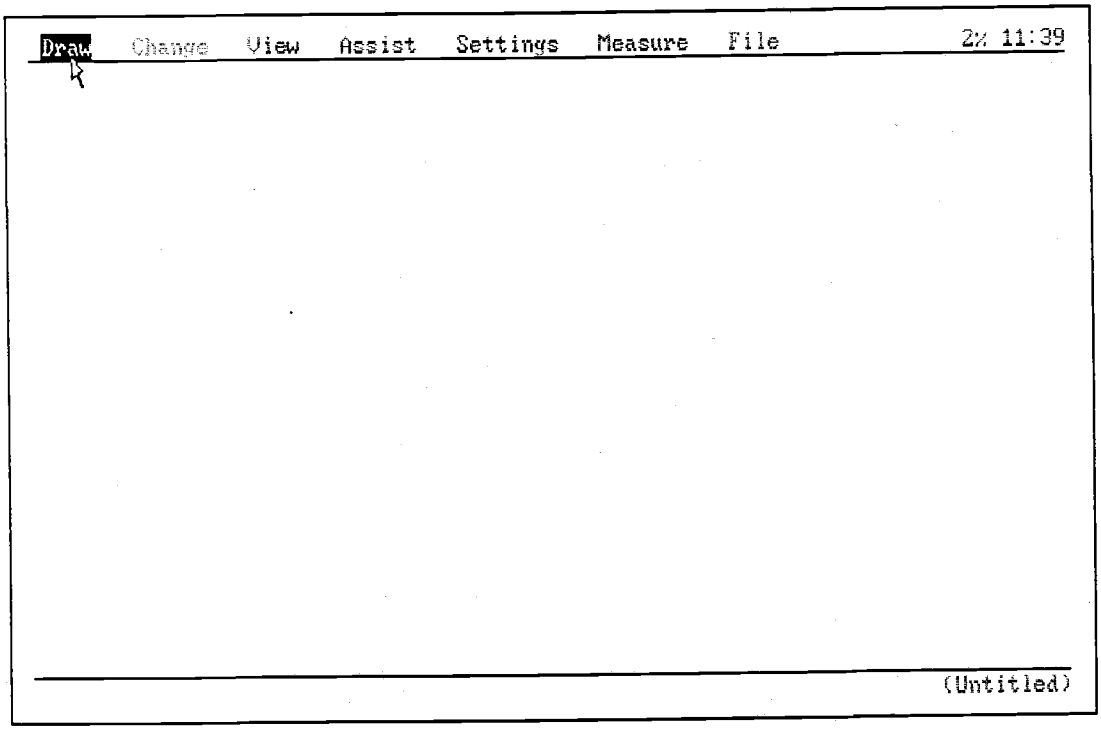
This is the AutoSketch screen. The arrow is called the cursor.

JUST LOOK AND READ



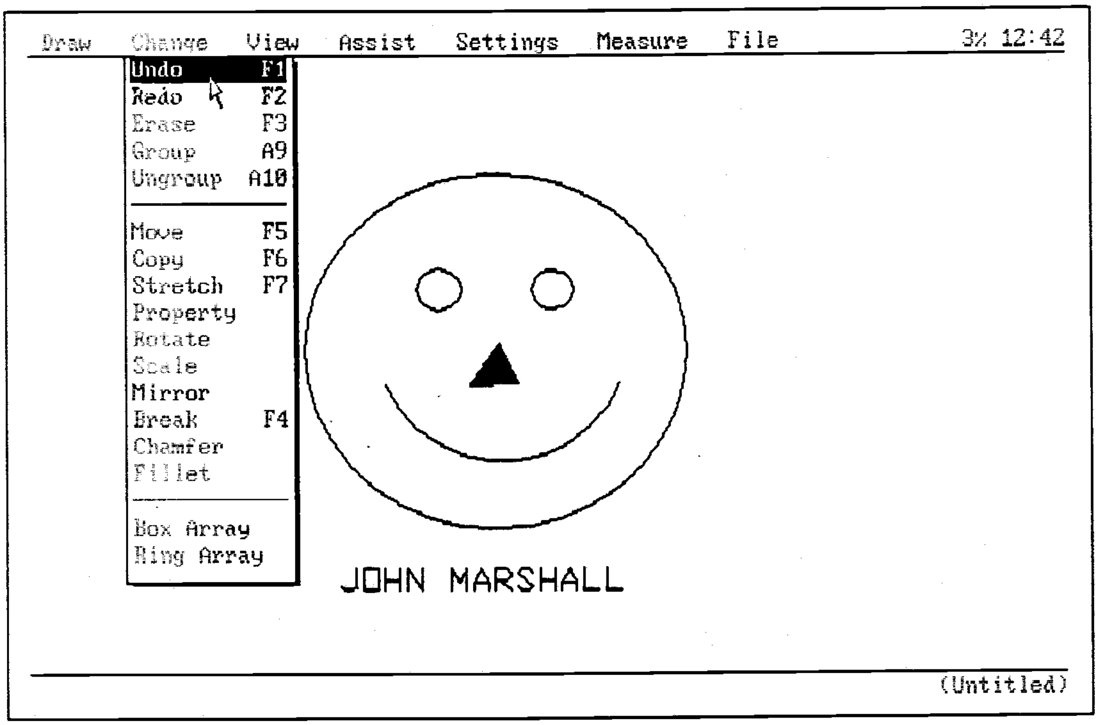
The cursor is pointing at the pull-down menu.

JUST LOOK AND READ



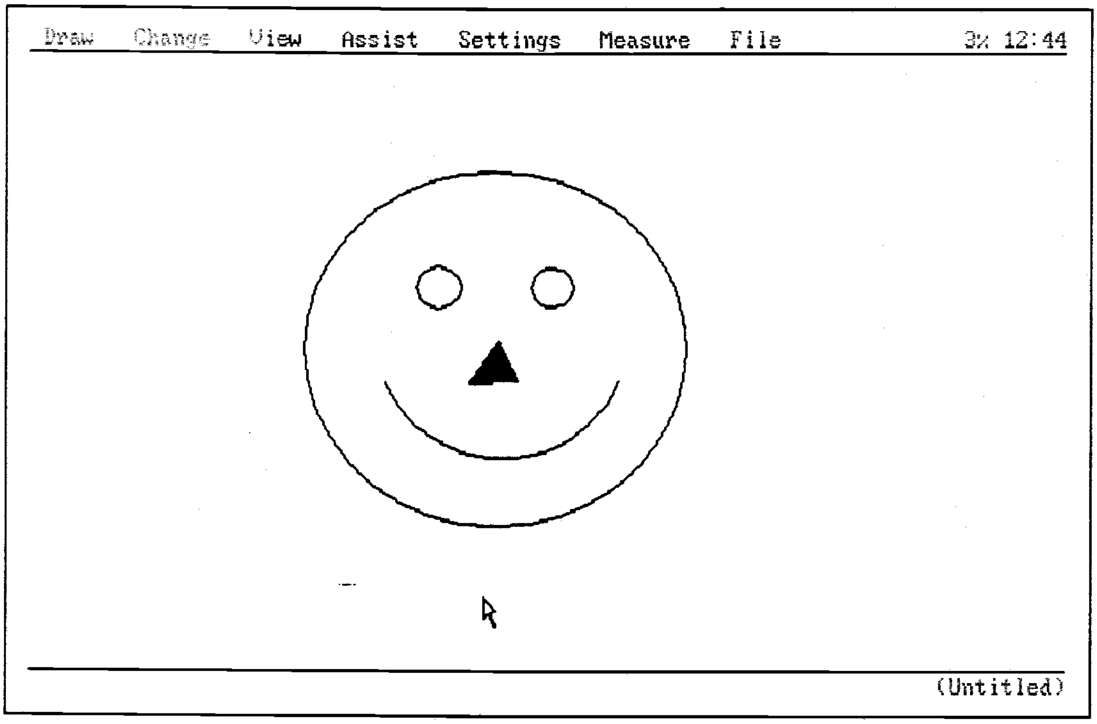
When you point the cursor at one of the pull-downs, it is highlighted.

JUST LOOK AND READ



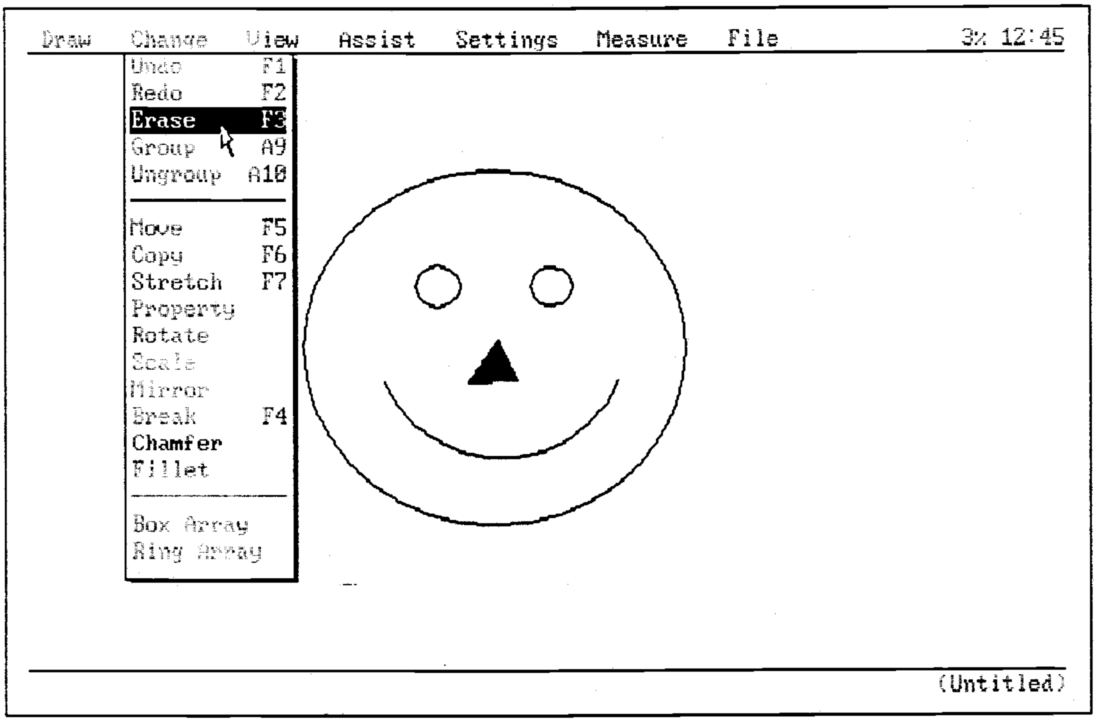
If you decide that you made a mistake, just select [Undo F1].

JUST LOOK AND READ



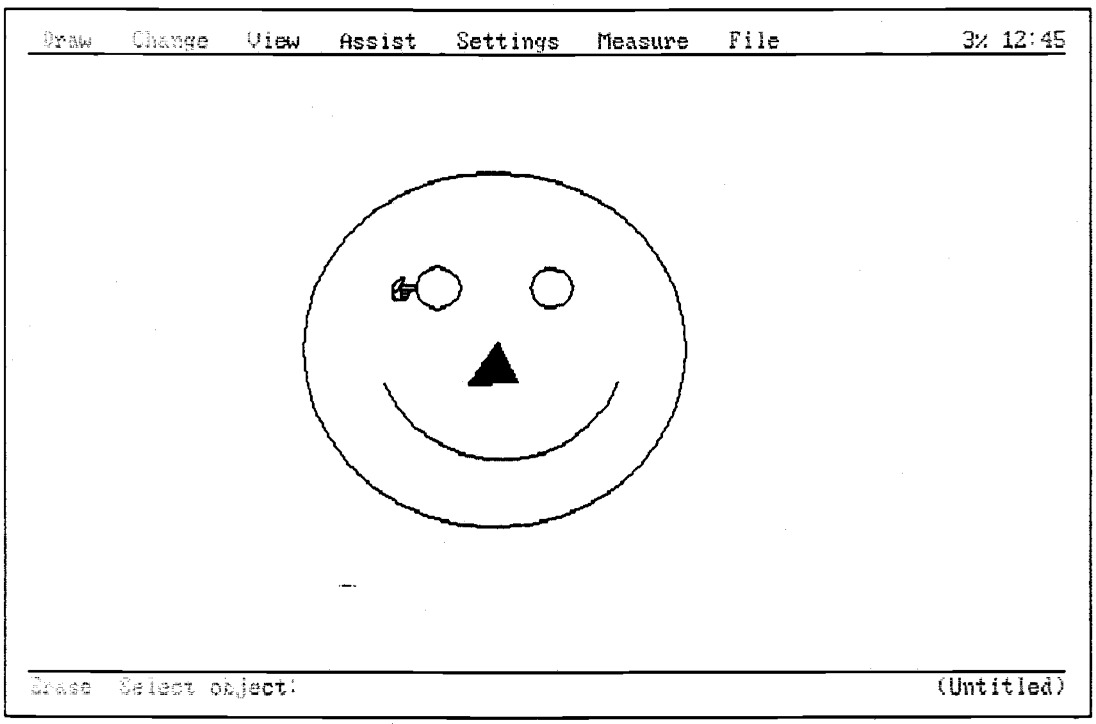
The last thing that you drew will be undone.

JUST LOOK AND READ



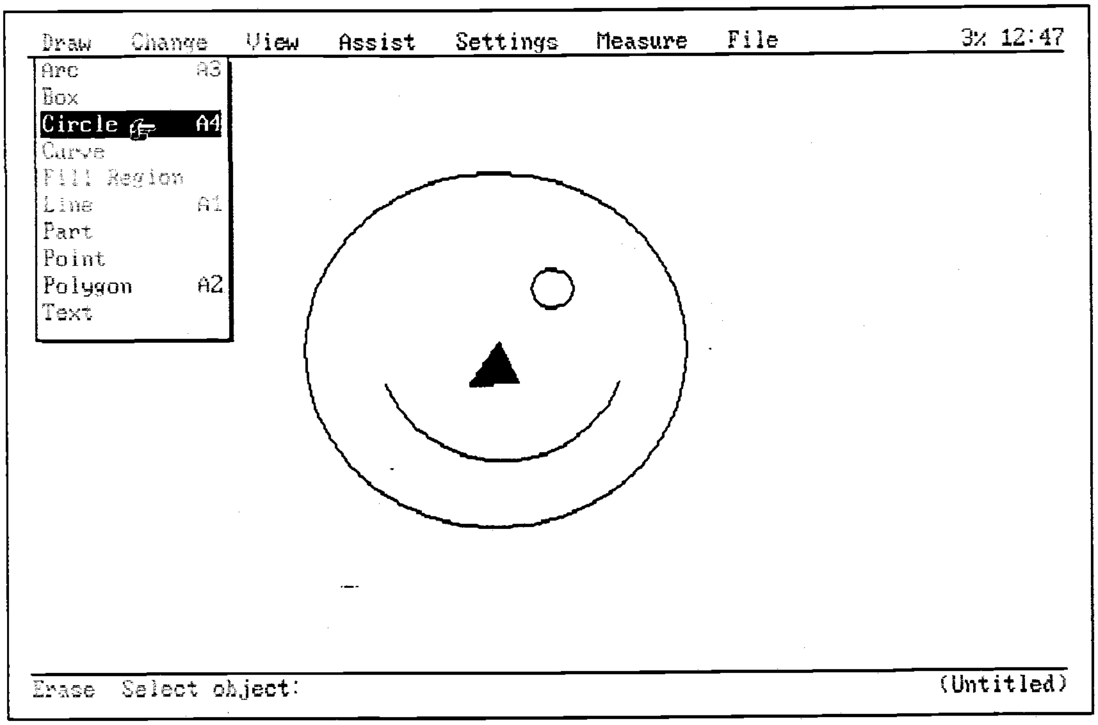
Or you can select [Erase F3].

JUST LOOK AND READ



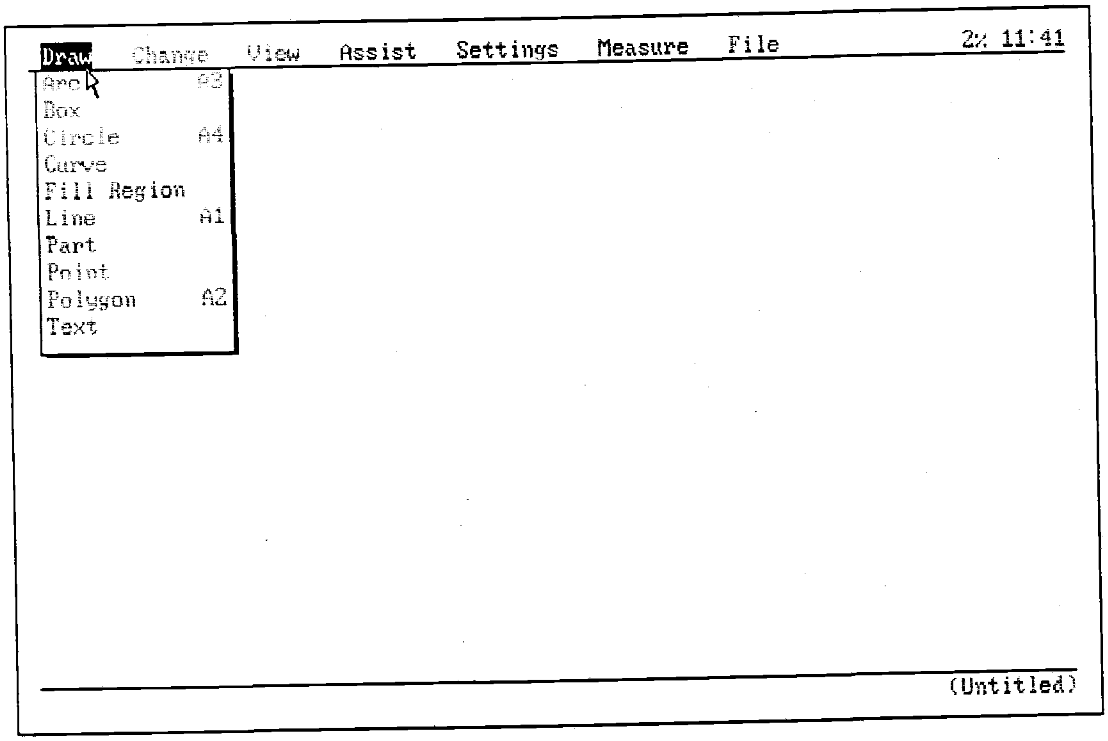
And use the pointing finger to point at the thing you want to erase.

JUST LOOK AND READ



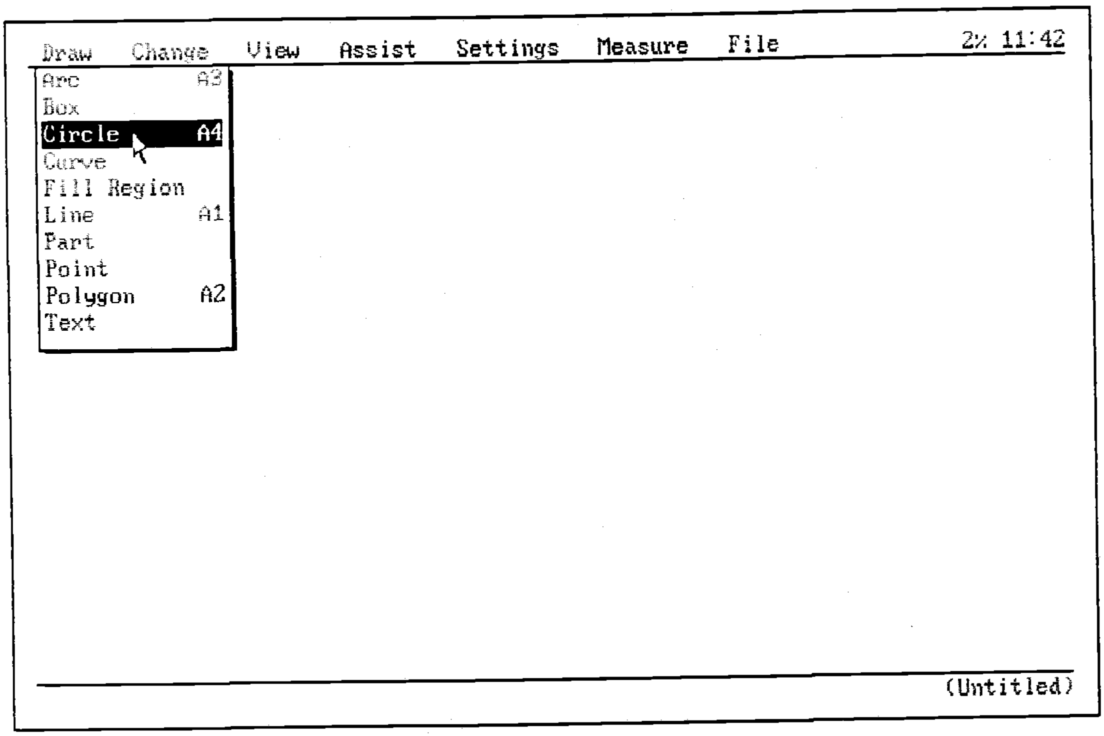
When you are done erasing, just pick the command you want to use.

JUST LOOK AND READ



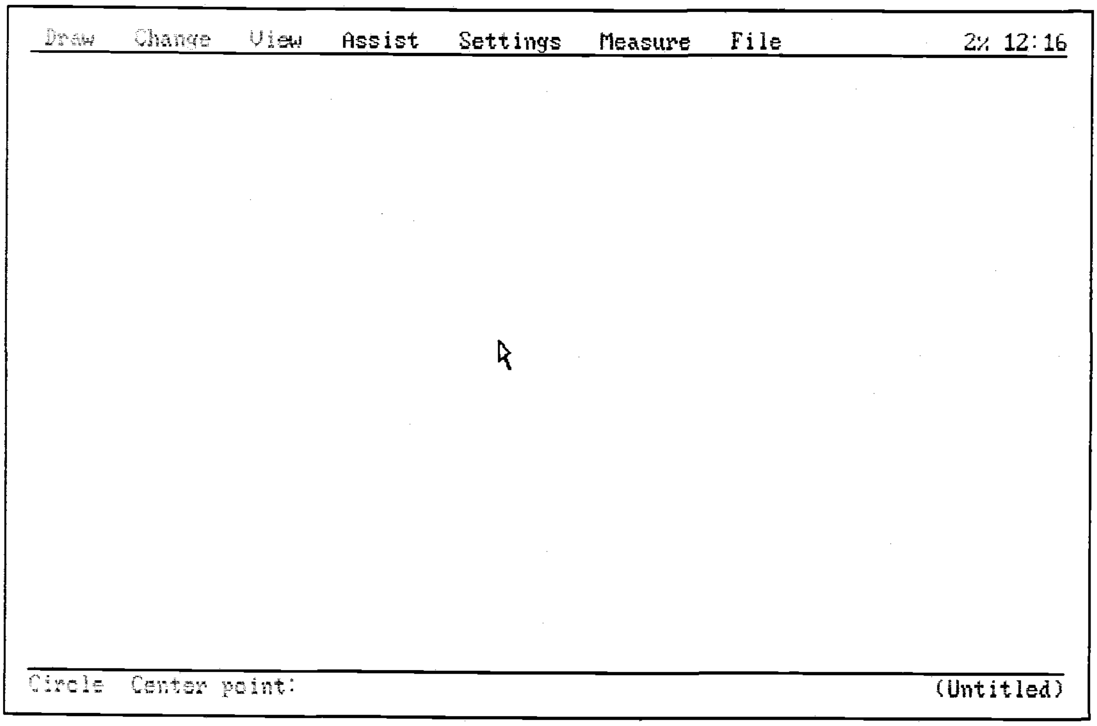
When you push the left mouse button, a menu box is pulled-down.

DO THIS



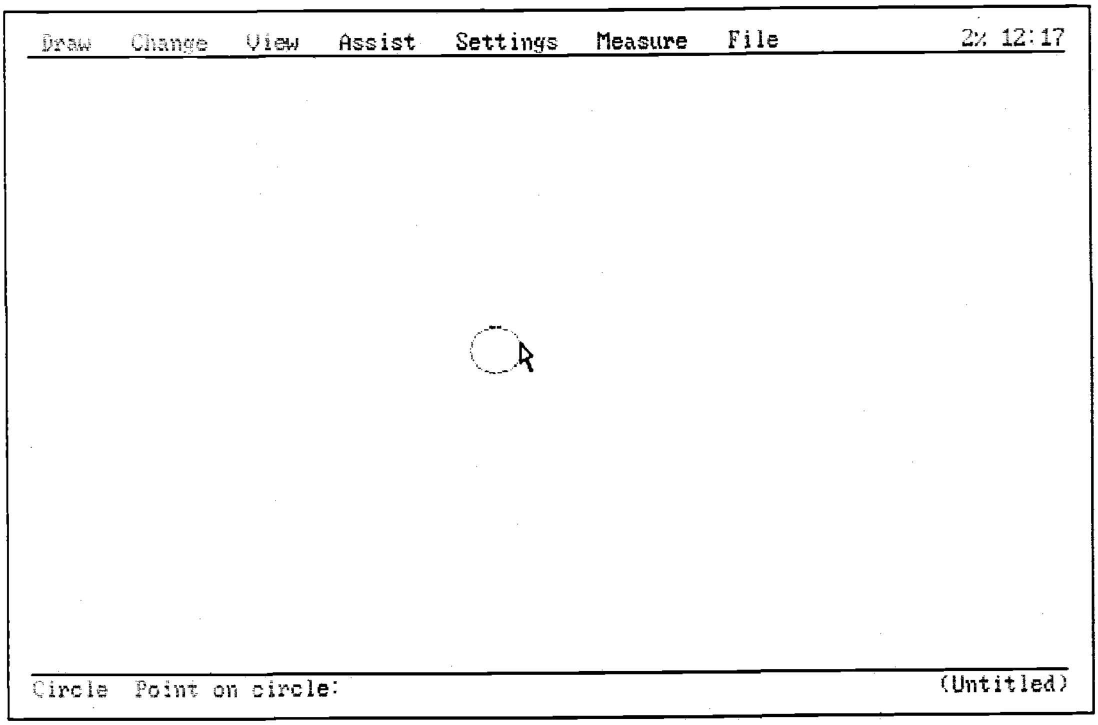
Move the cursor to highlight [Circle A4] and push the left button.

DO THIS



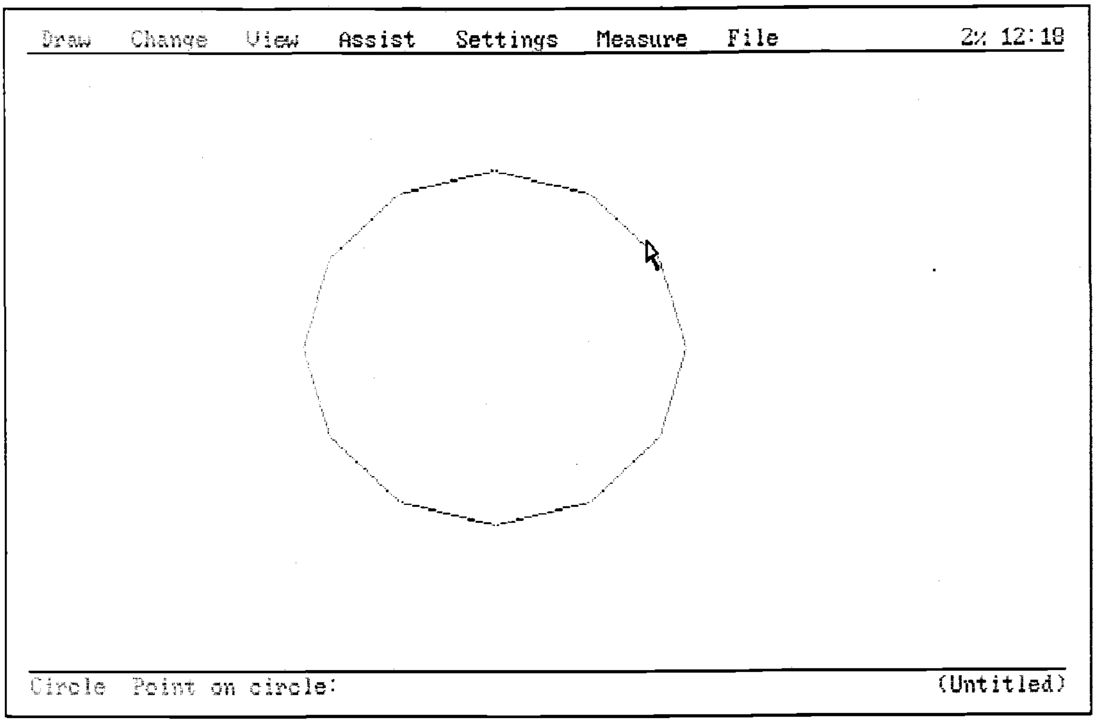
Move the cursor to the center of the screen and push the left button.

DO THIS



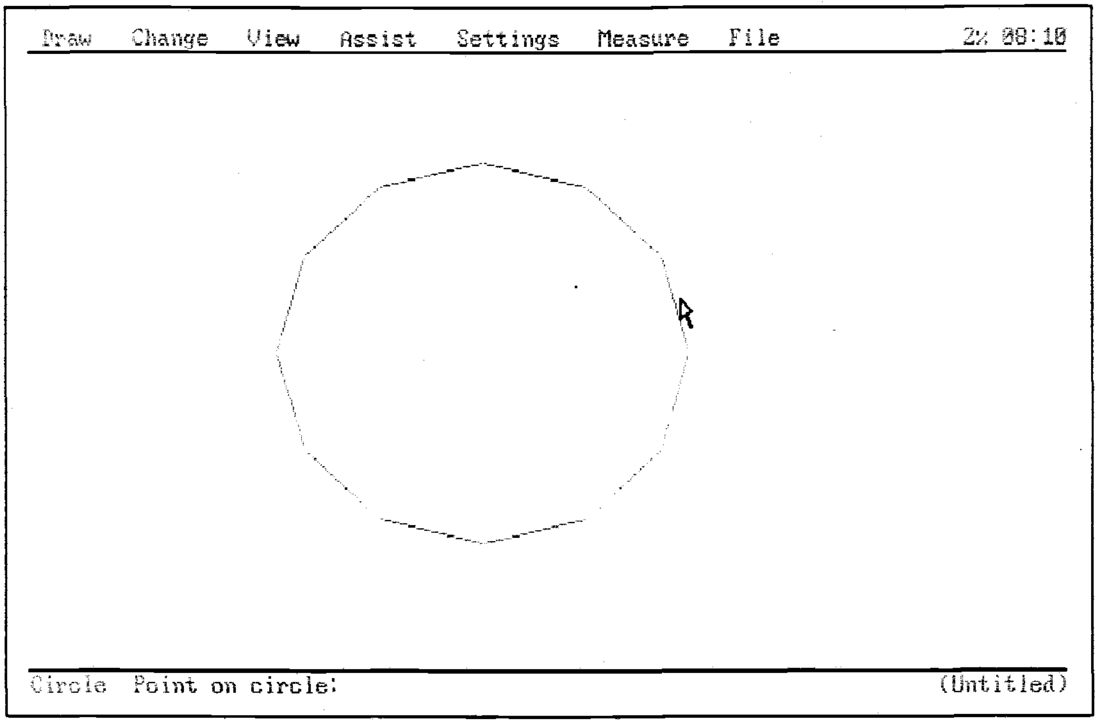
Now, move the cursor and you will see a circle attached to it.

DO THIS



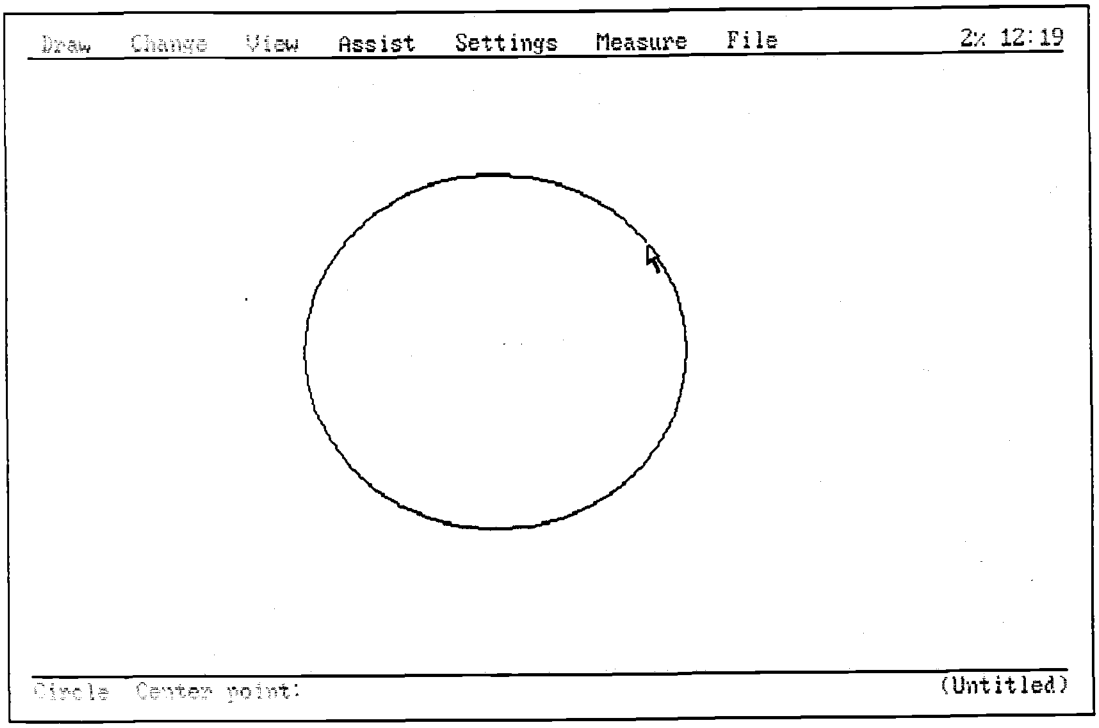
Now, move the cursor to make a circle about this big.

DO THIS



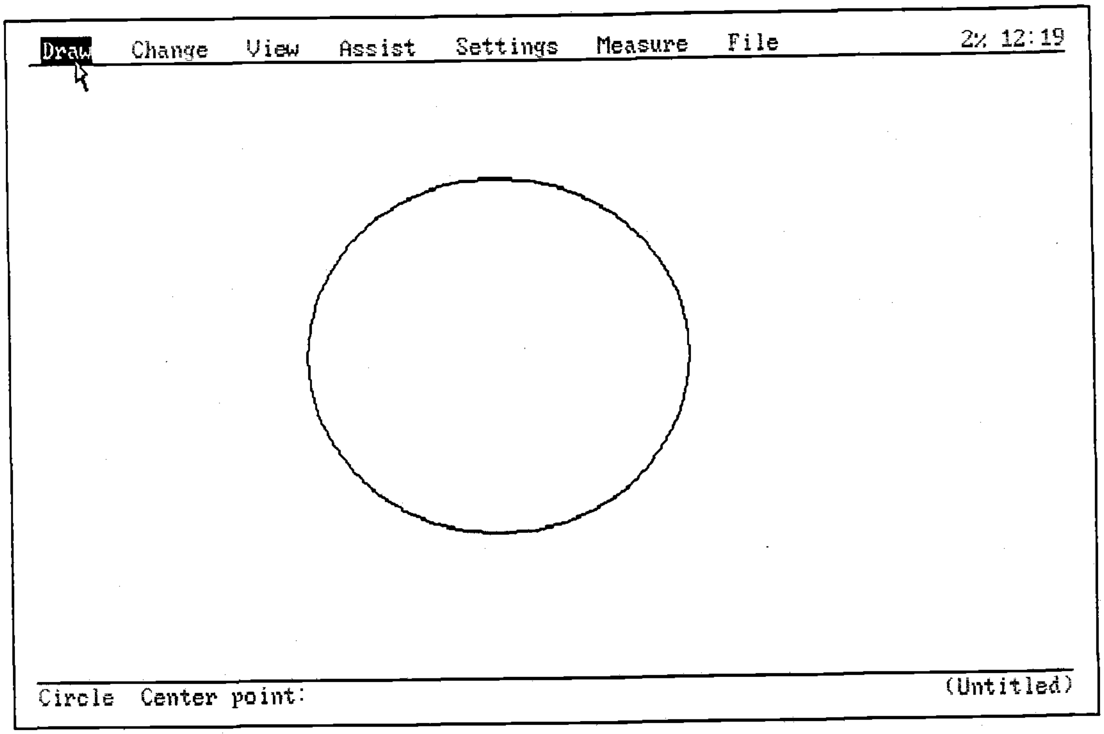
Now, push the left button on the mouse.

DO THIS



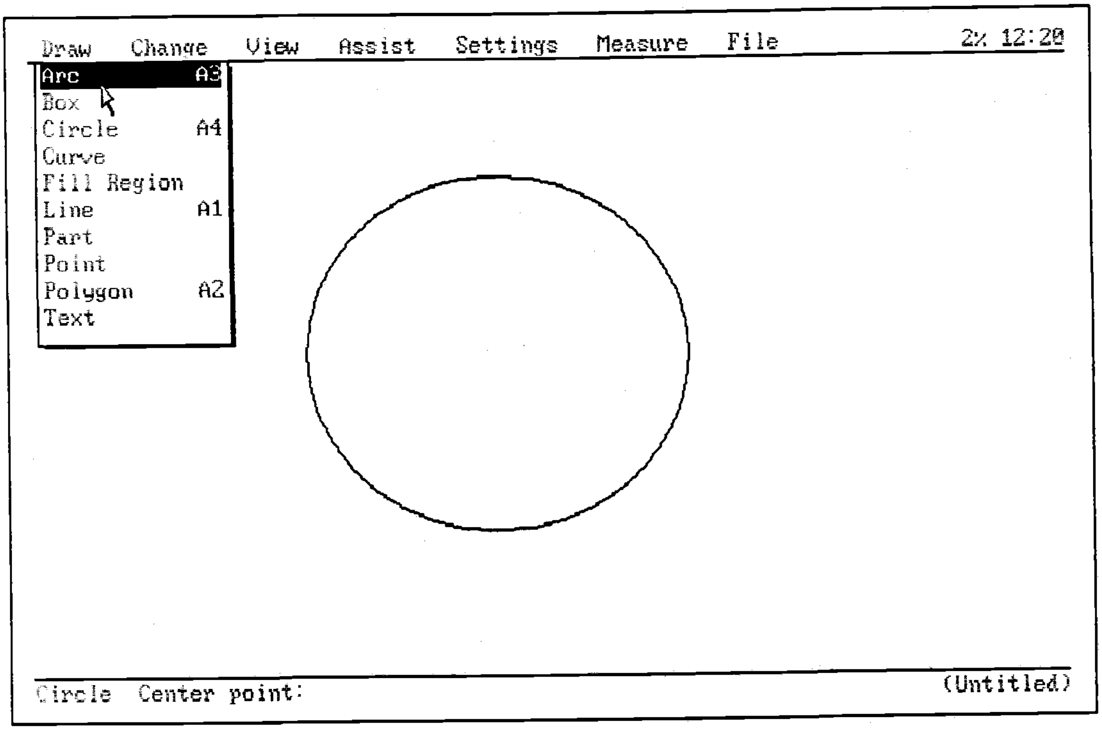
The finished circle is now drawn.

JUST LOOK AND READ



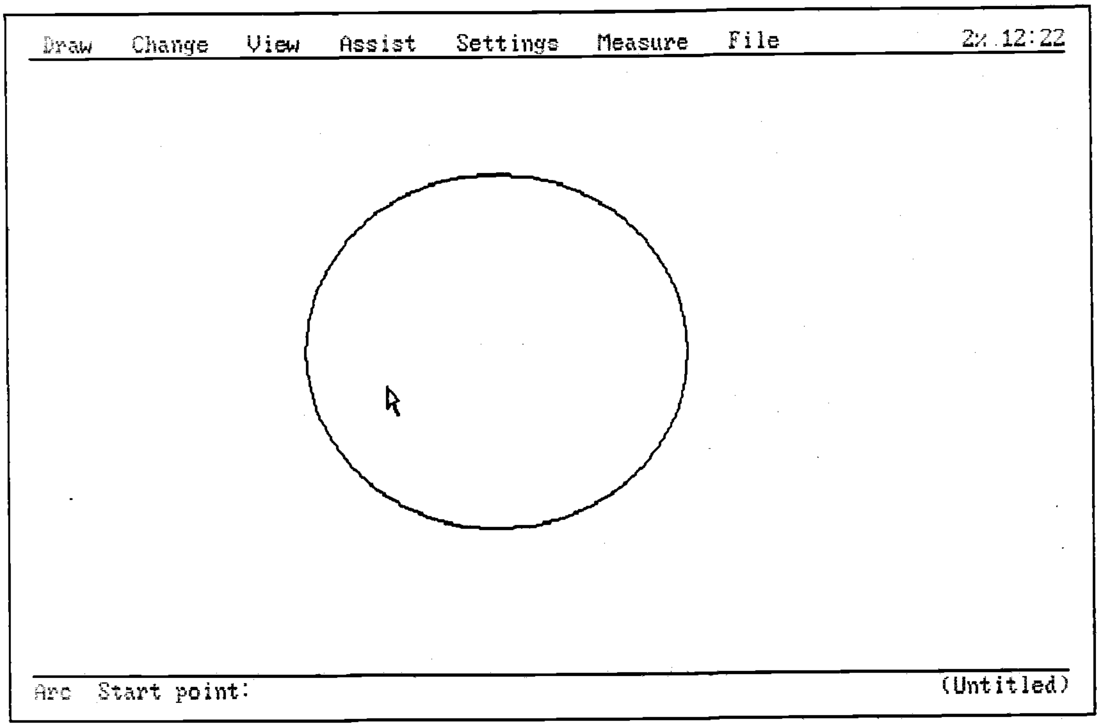
Pick the pull-down "Draw" again.

DO THIS



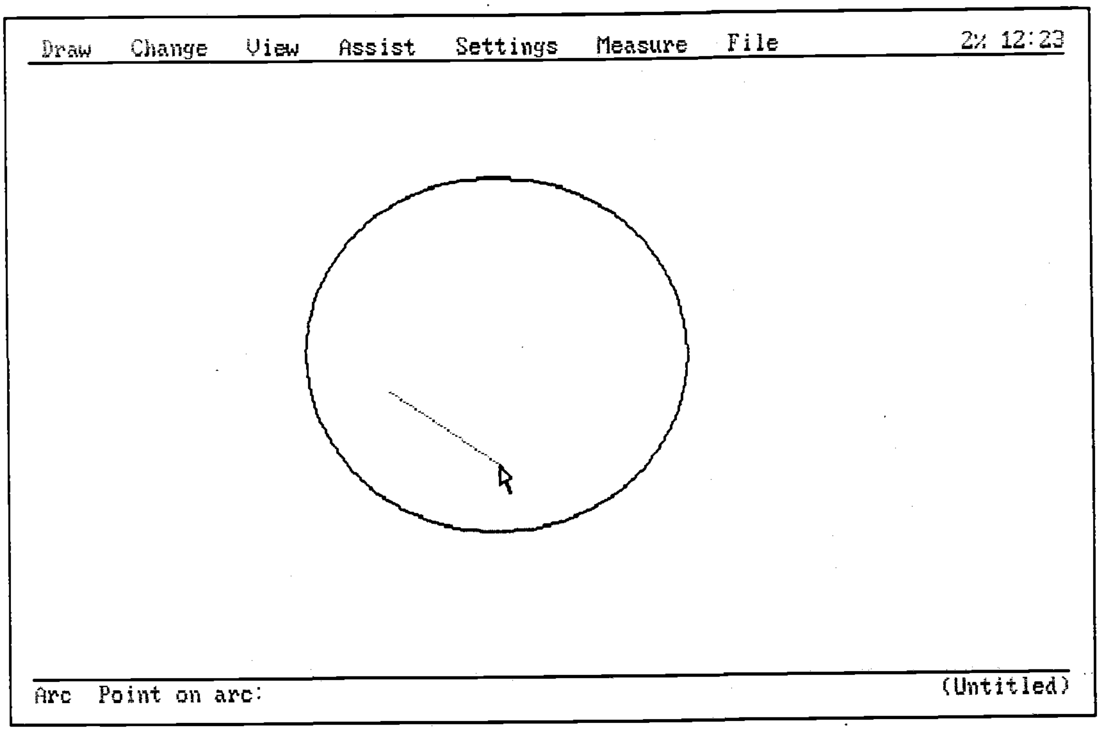
Pick the [Arc A3] command.

DO THIS



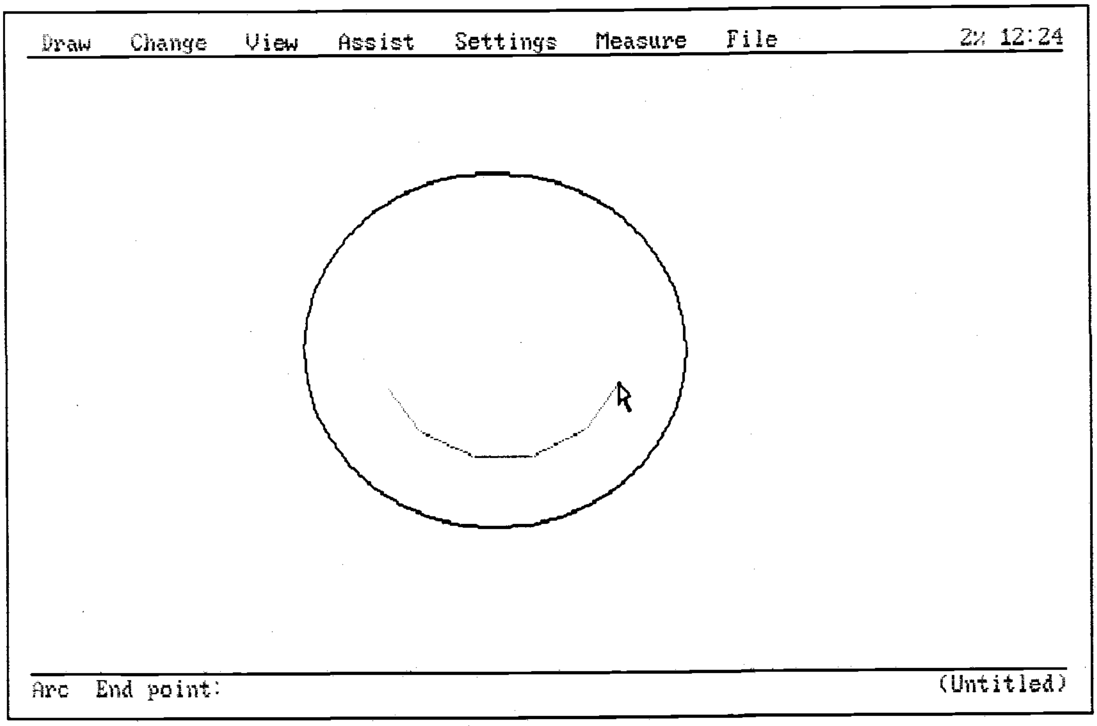
Move the cursor inside the circle, and push the left mouse button.

DO THIS



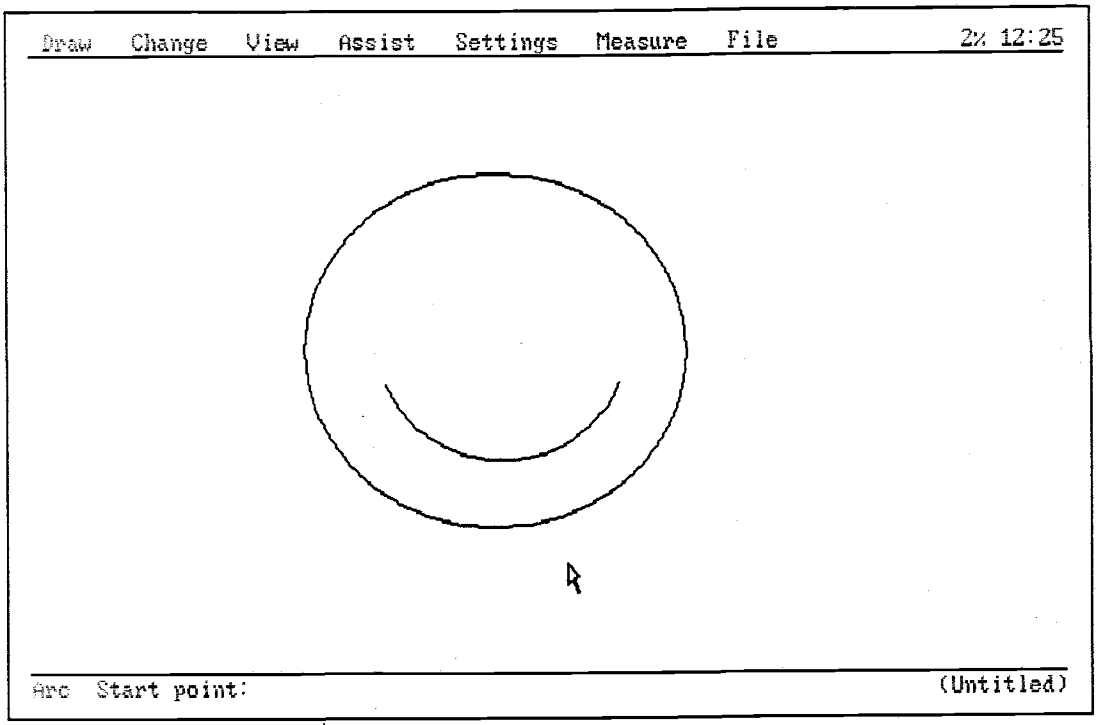
Now, move the cursor to this next spot and push the left mouse button.

DO THIS



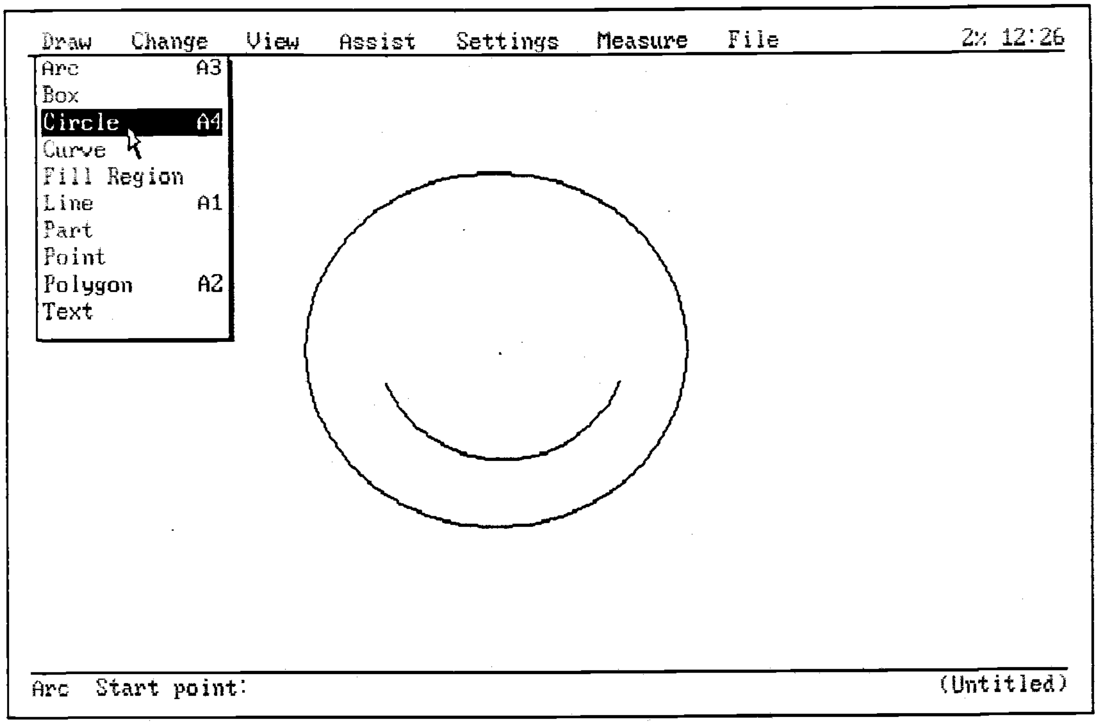
Move the cursor to the next spot and push the left mouse button again.

DO THIS



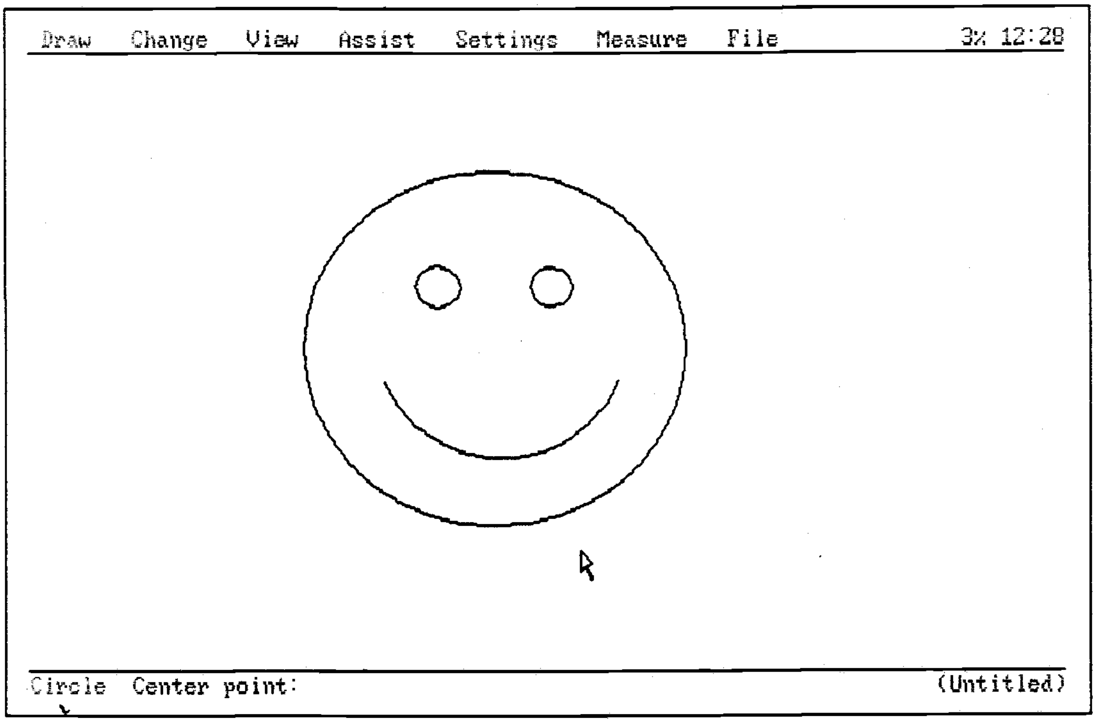
You just created a nice smile for our happy face.

JUST LOOK AND READ



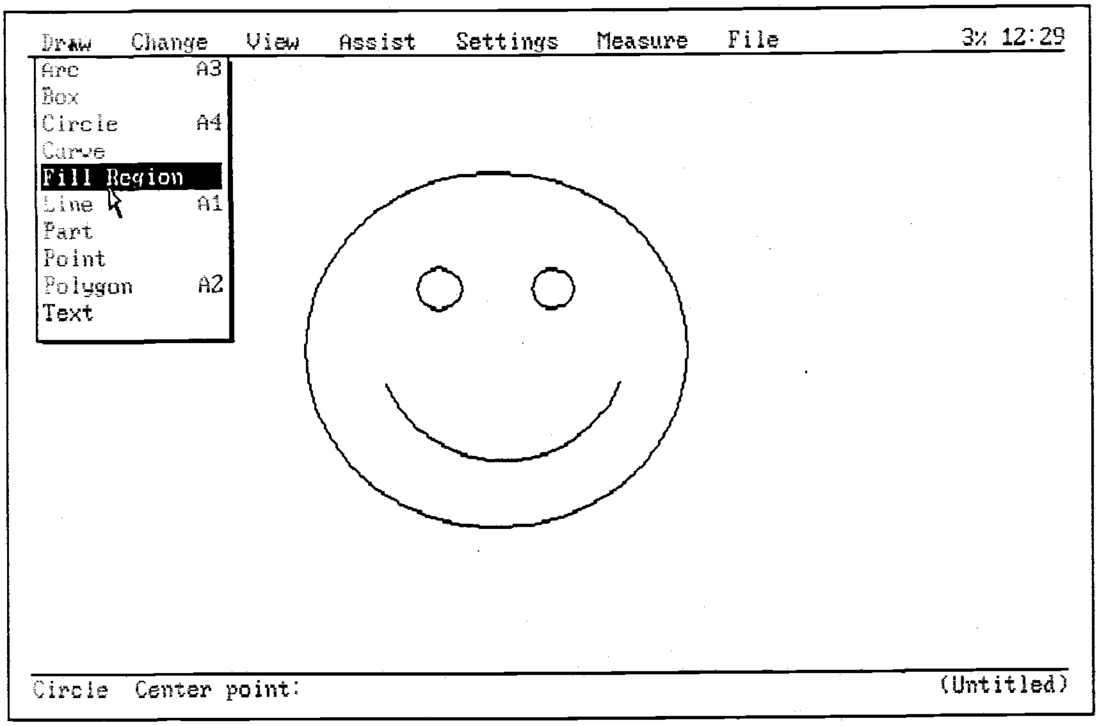
Let's use the [Circle A4] command again to make the faces eyes.

DO THIS



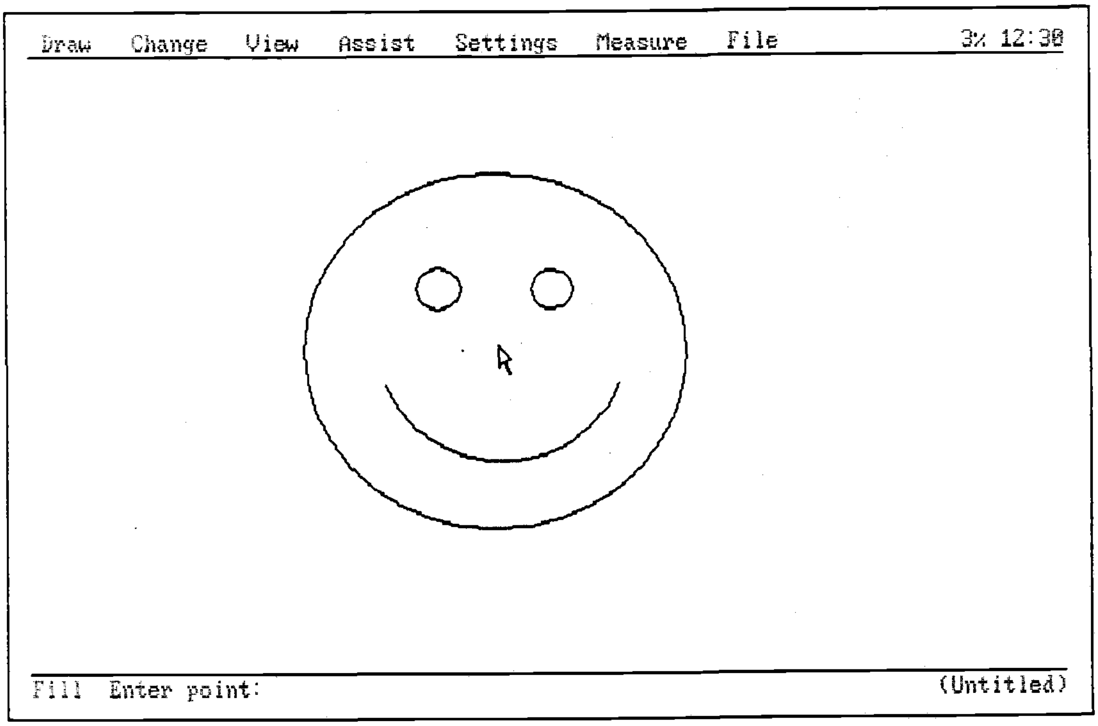
Here's the happy face with two eyes.

JUST LOOK AND READ



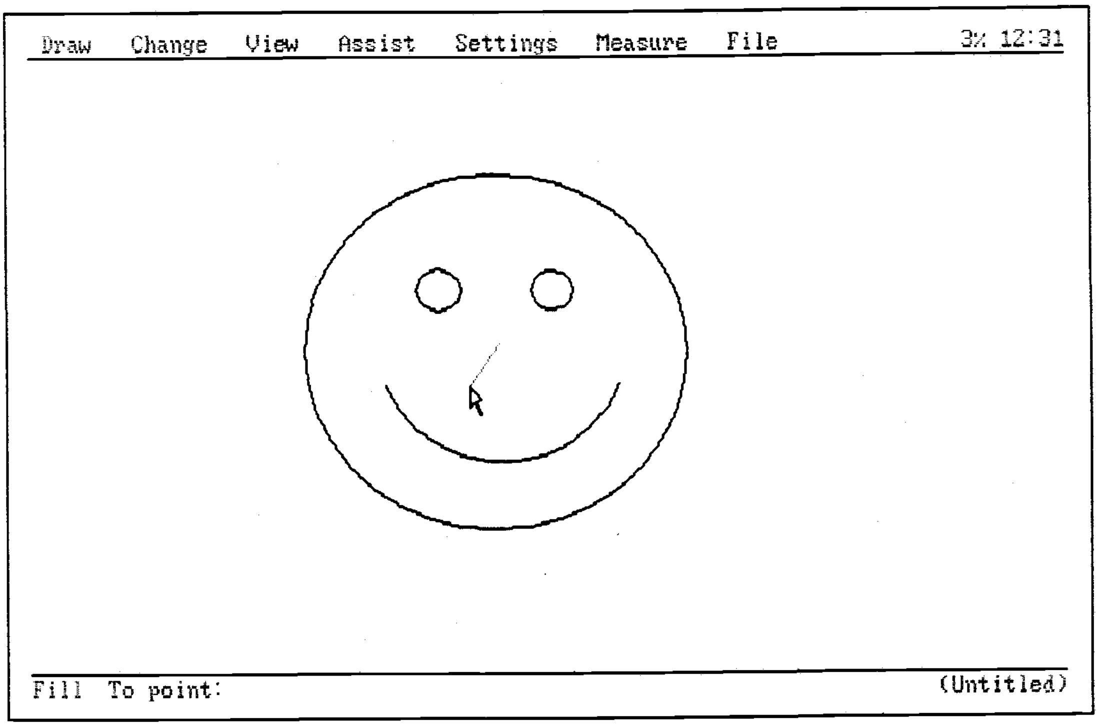
Now, select [Fill Region] and let's add the faces nose.

DO THIS



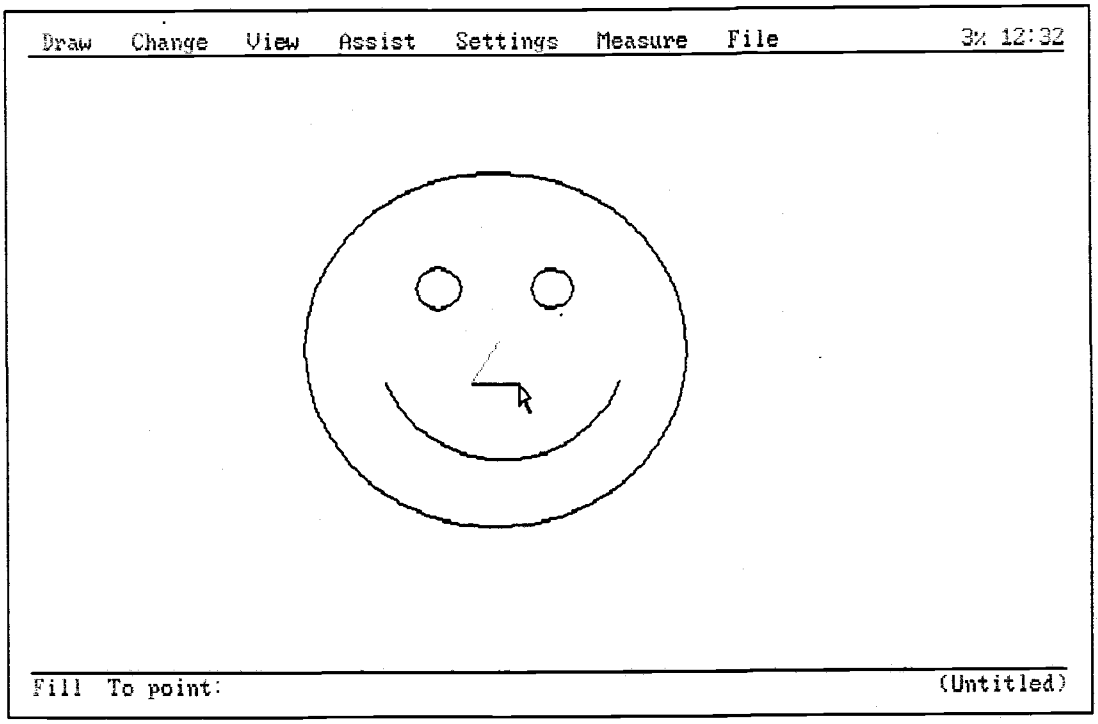
Move the cursor to the spot shown and push the left mouse button.

DO THIS



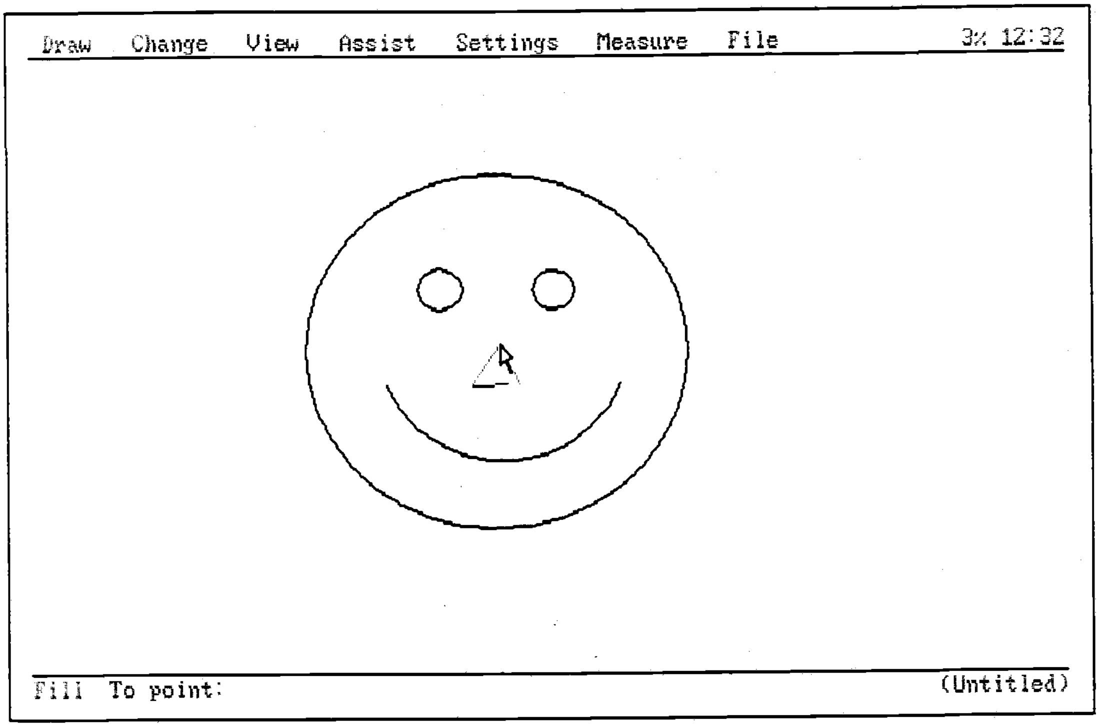
Now move to here and push the left mouse button again.

DO THIS



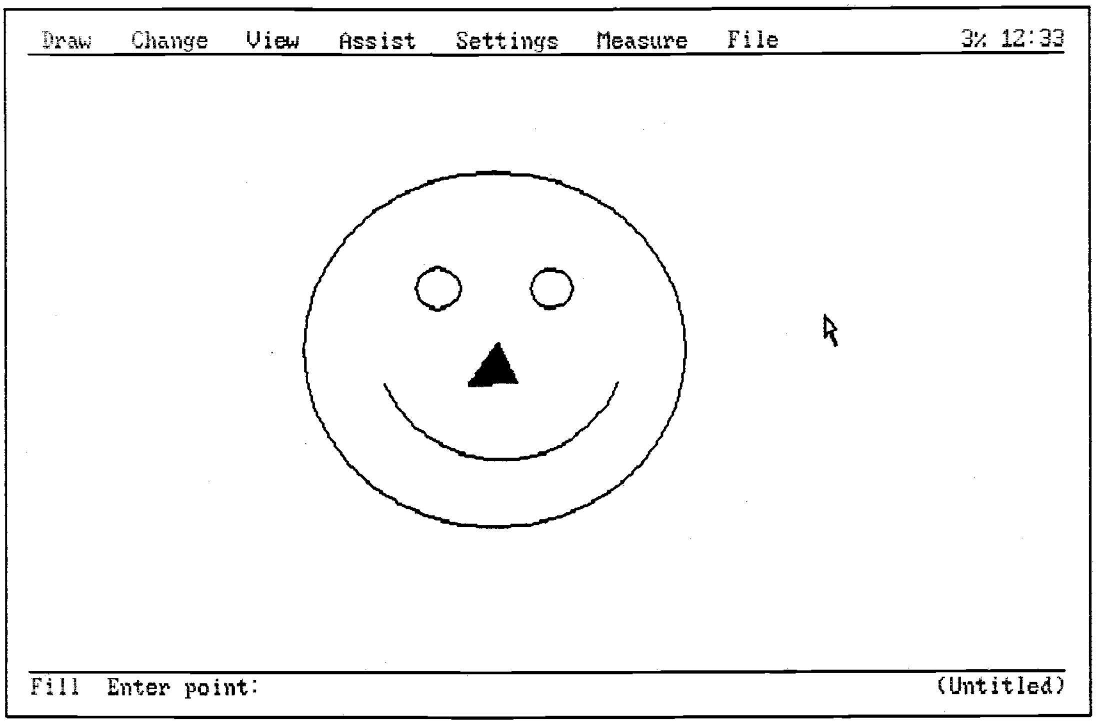
Now move to here and push the left mouse button again.

DO THIS



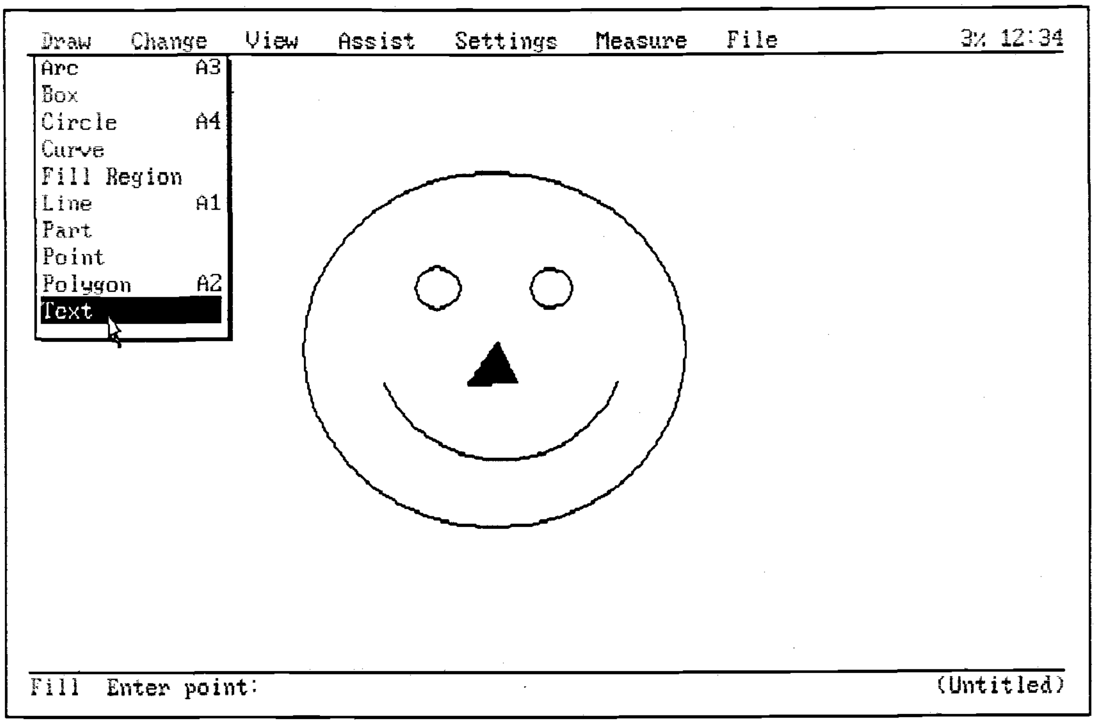
Now move to the starting point and push the button one more time.

DO THIS



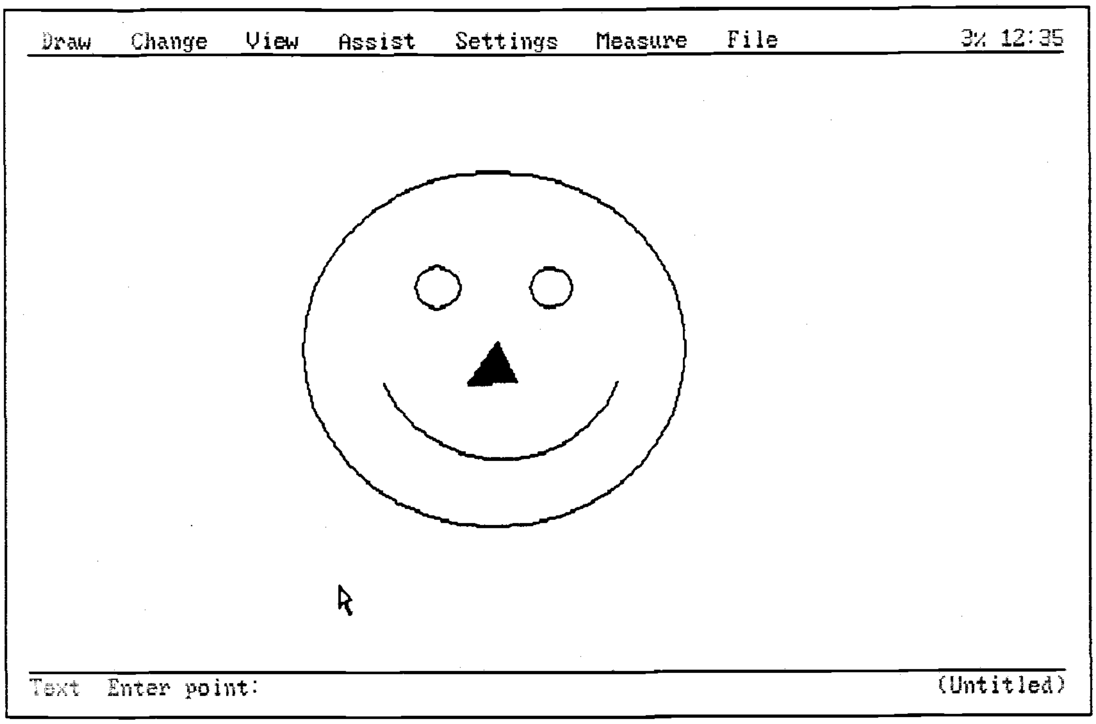
What a happy face.

JUST LOOK AND READ



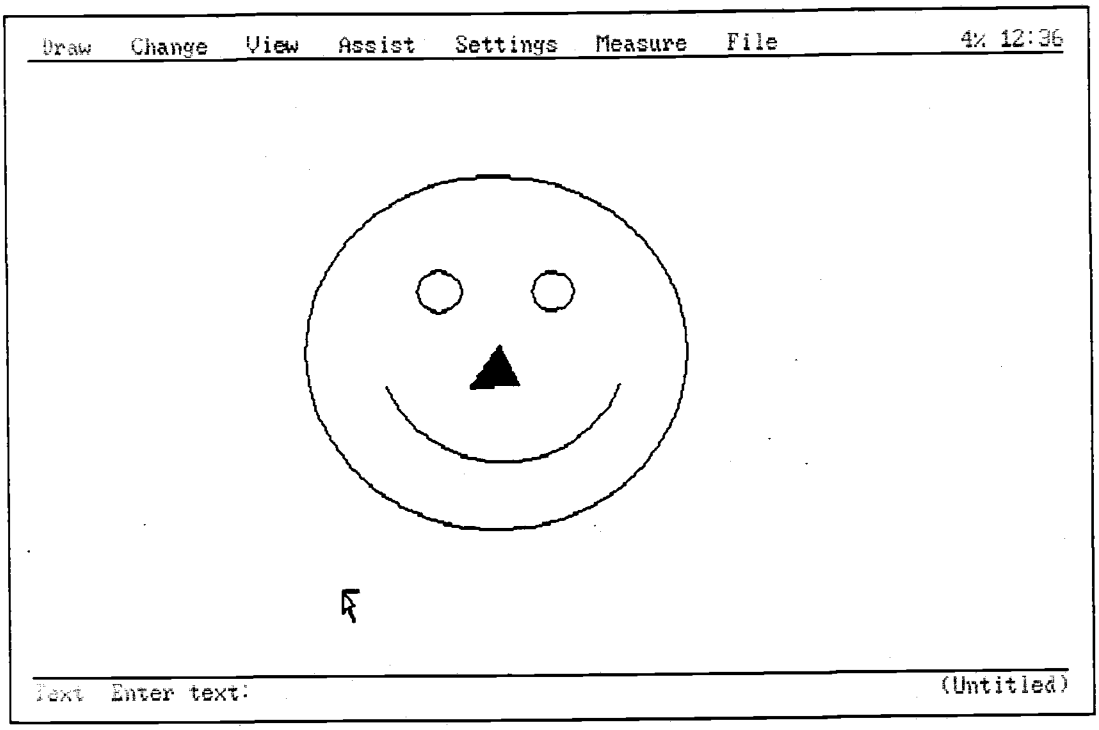
Now let's add our name. Select [Text].

DO THIS



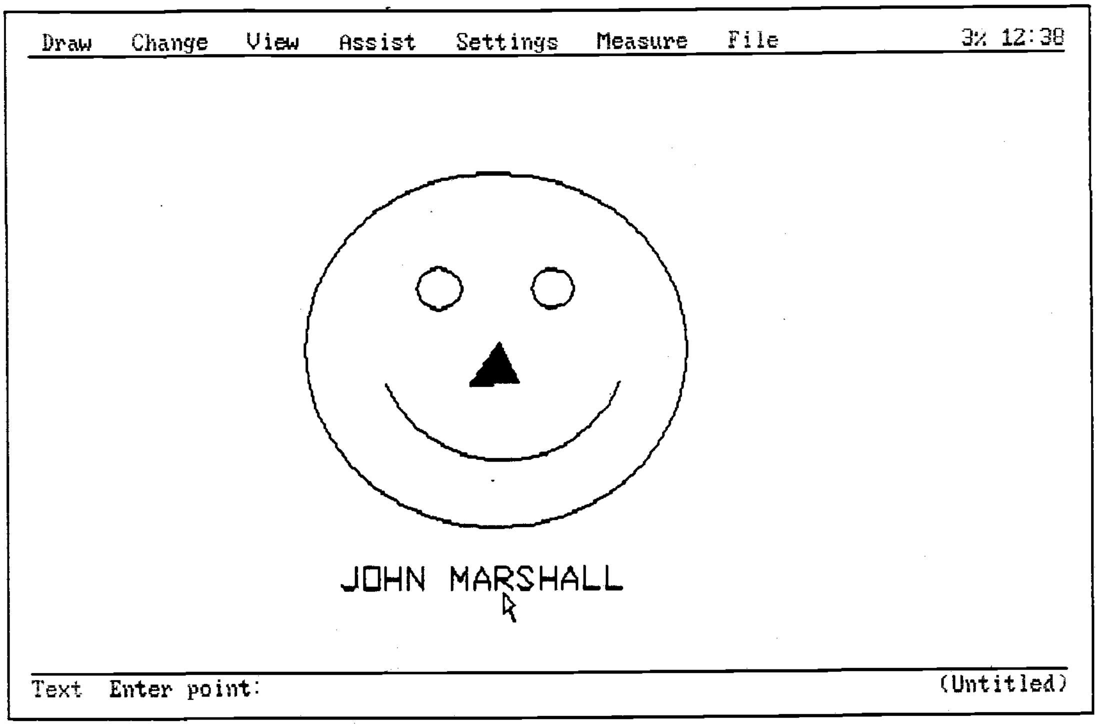
Move the cursor to the point shown.

DO THIS



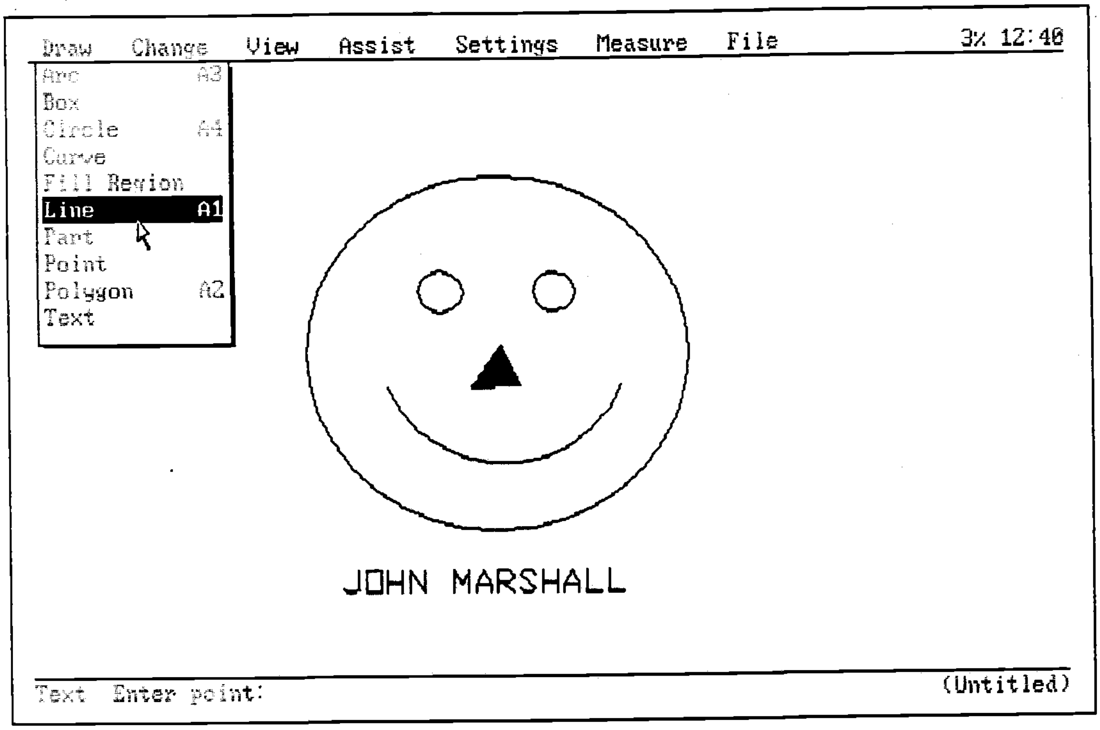
Now, type your name.

DO THIS



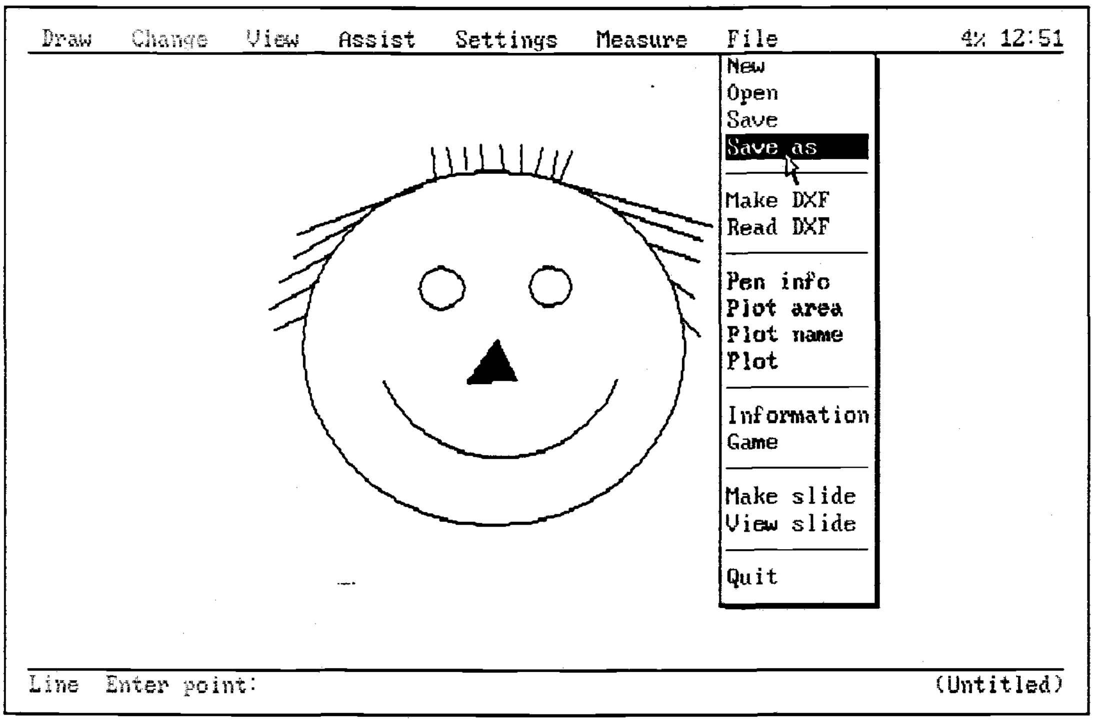
Is your drawing like this one? If it is different, that's OK.

JUST LOOK AND READ



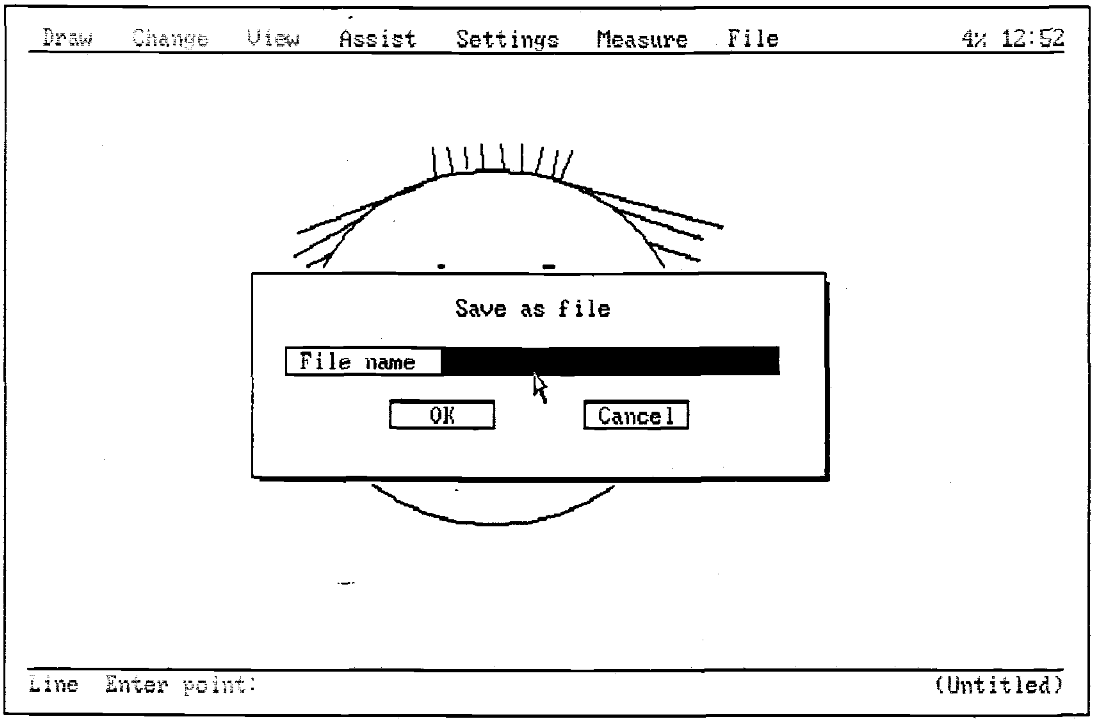
Try other commands like [Line A1] to make hair or to just have fun.

DO THIS



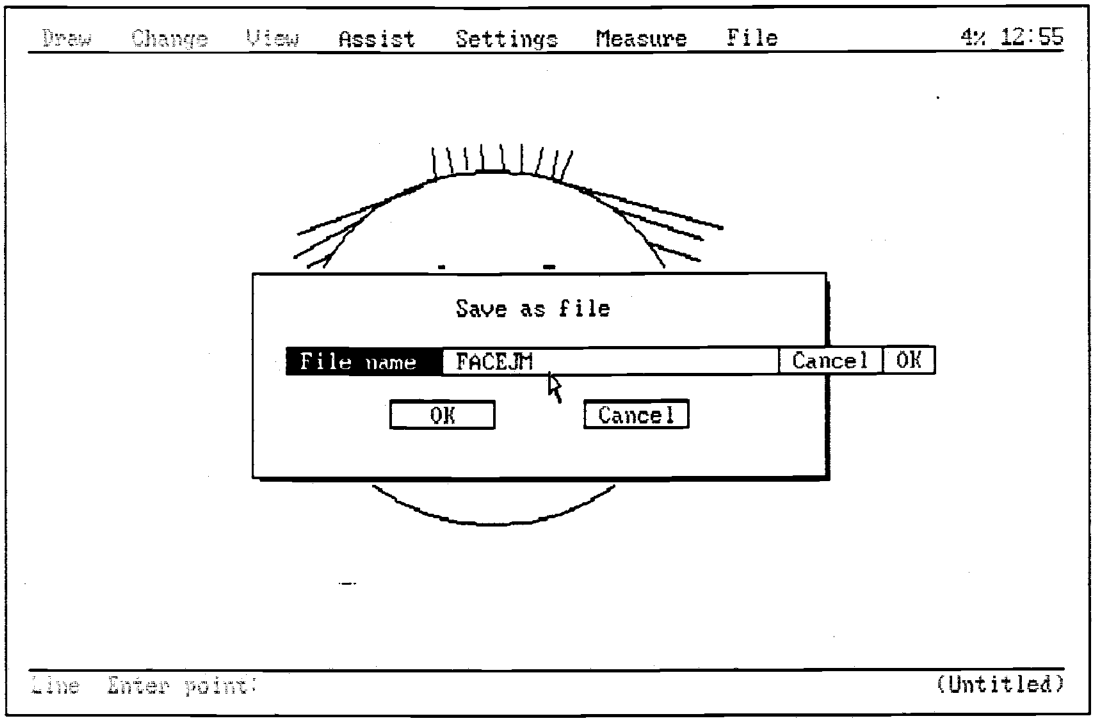
To save your drawing, select [Save as].

DO THIS



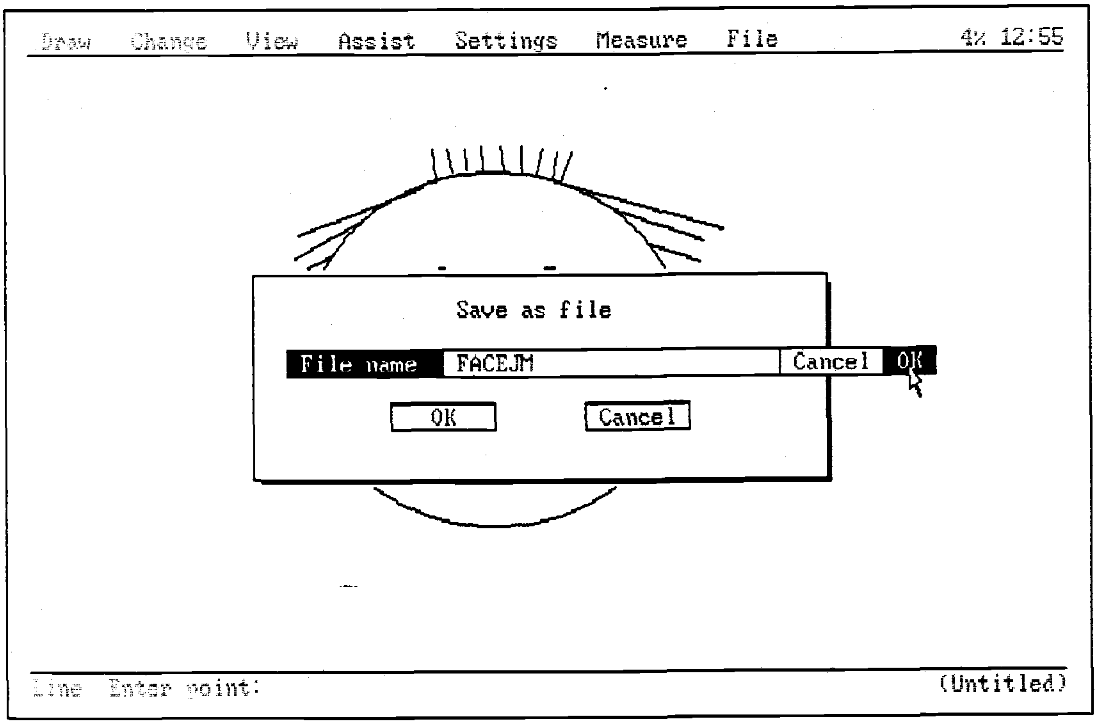
Move the cursor to highlight the box, and push the button

DO THIS



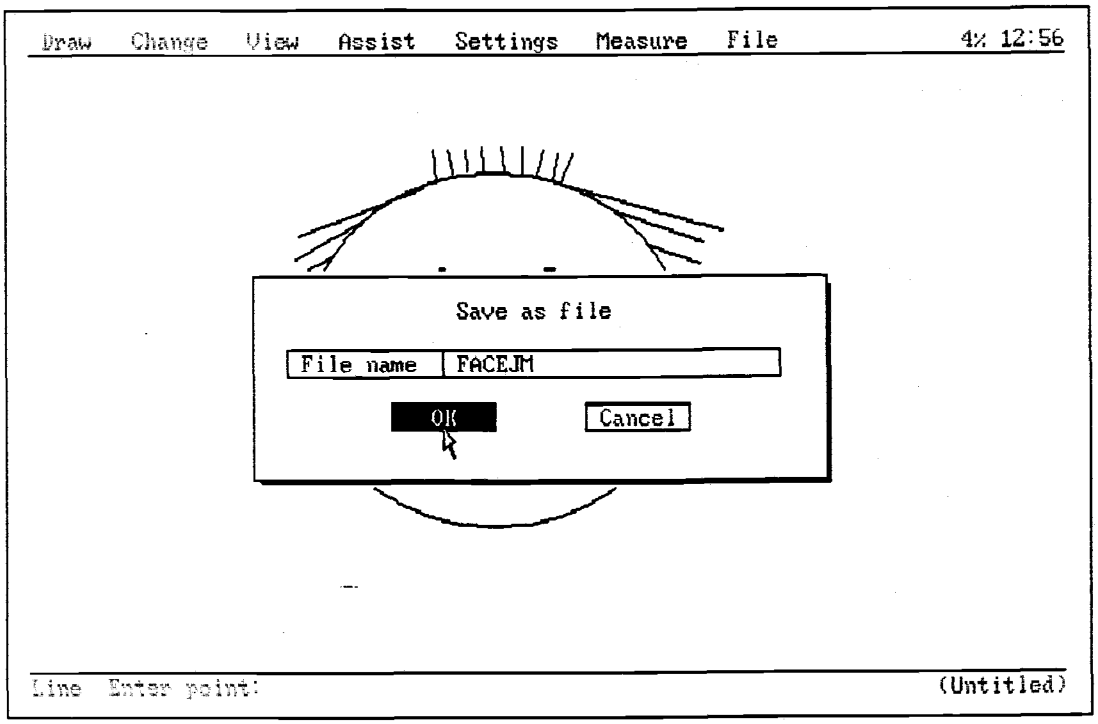
Now type FACE and your initials JM, like this FACEJM

DO THIS



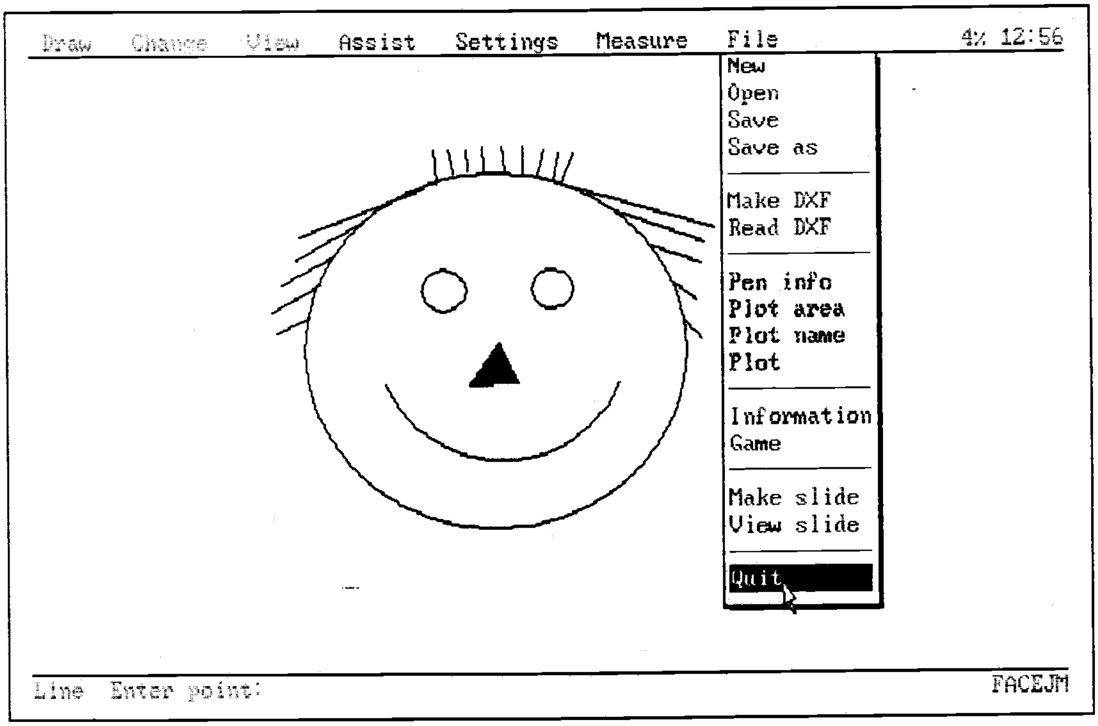
Now click [OK].

DO THIS



Now click [OK] again.

DO THIS



Now select [Quit] and you are done for now.

DO THIS

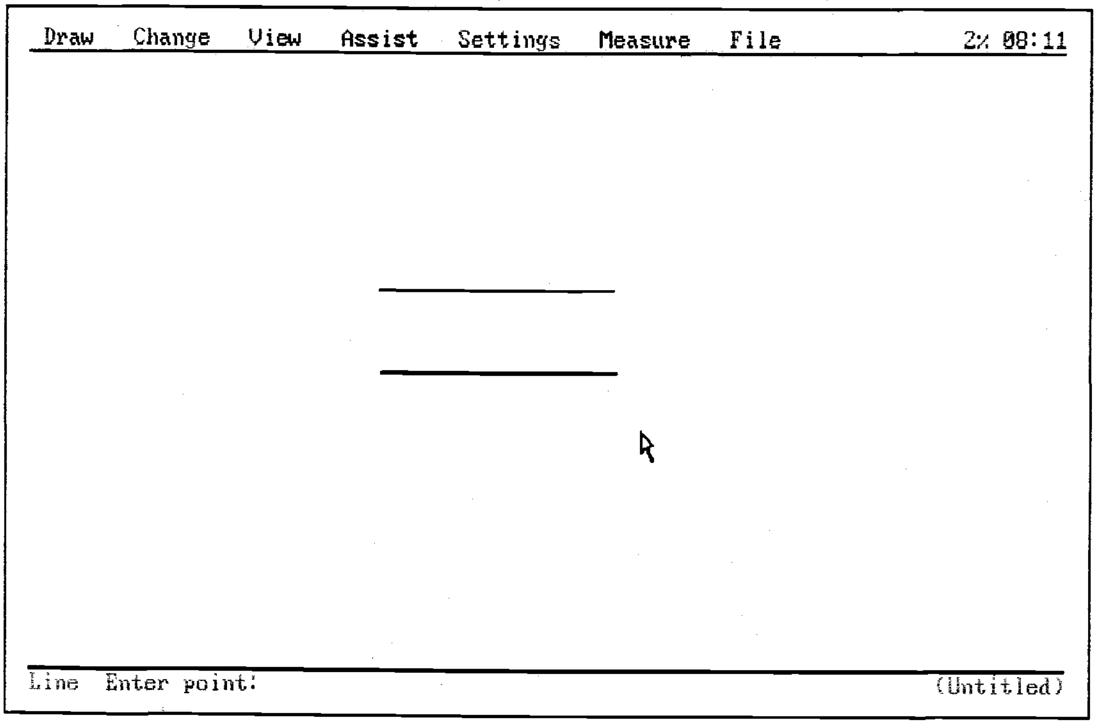
This is the end of the first part of this project.

Part 2

On this part of the project, you are to draw two horizontal lines like the ones shown below. After you draw these lines, you are to create anything you want, but you must use these two lines as part of the drawing. You can draw between the lines, on top of the lines, or not touching the lines. It is up to you. Just have fun, and try and make something that no one else will make.

After you have finished your drawing, use the [Text] command and add a title somewhere on the drawing. When you finish, save the drawing as COMP and your initials. Like this: COMPJM

You may start now.



Draw the two lines like this. It's OK if they are not "perfect".

THIS IS THE END OF THE SESSION

The Creative Technologies Project

by Mark L. Merickel

in cooperation with
Autodesk, Inc., the Novato School District,
and Oregon State University

AUTOSKETCH®

The Workstation Project
AUTOSKETCH
Puzzle Building and Space Relations
Instruction Booklet

2

Introduction

The creative technologies project is designed to introduce students to new and exciting ways to use computers. The workstation project introduces students to the processes of developing and manipulating two-dimensional geometric figures. It is believed that this development and interaction with computer graphic models will enhance certain cognitive abilities. Included in these are: spatial and visual abilities, displacement and transformational abilities, creativity, and spatially related problem solving.

To complete this project the participants will use a computer workstation operating under DOS. The participants will be using the AutoSketch (R) program by Autodesk, Inc.

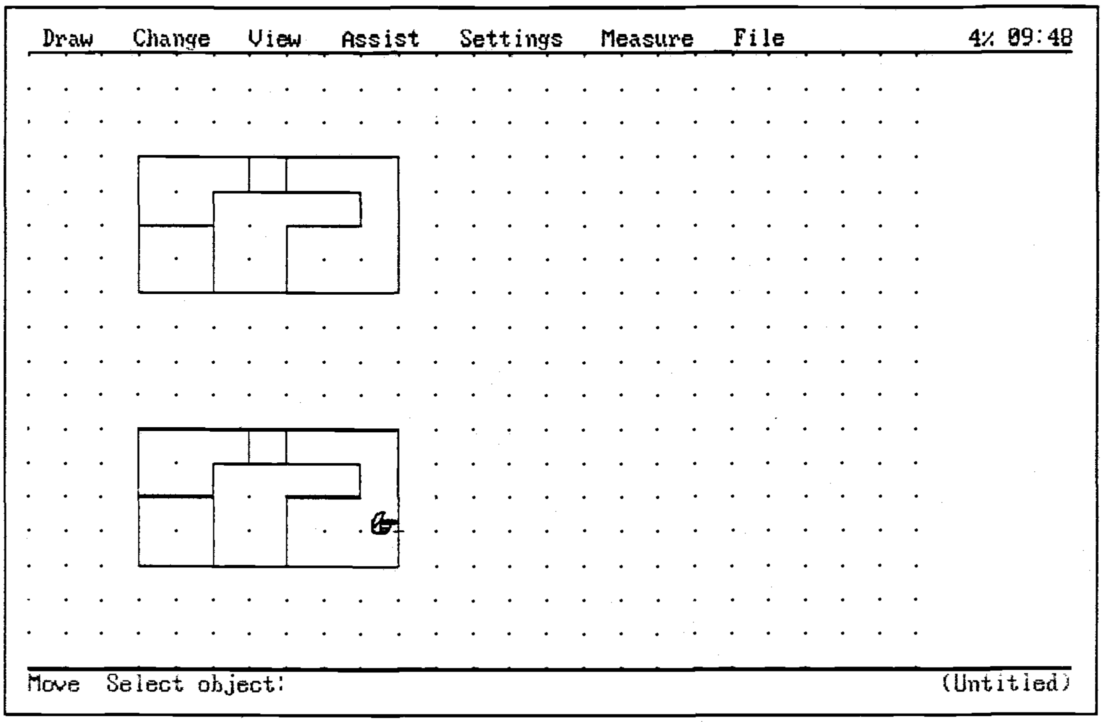
The following pages contain the instructions for the project. Each participant should be seated at a workstation before starting the project. The instructions are designed to be followed, and performed on the workstations, in sequence. If the participant becomes confused at any time throughout the project, it is recommended that the "instructor" assist them with restarting the project from the beginning.

Instructions

The following pages show you how to develop and modify geometric shapes. The model that you develop may not match the example shown in this instruction booklet. That's OK.

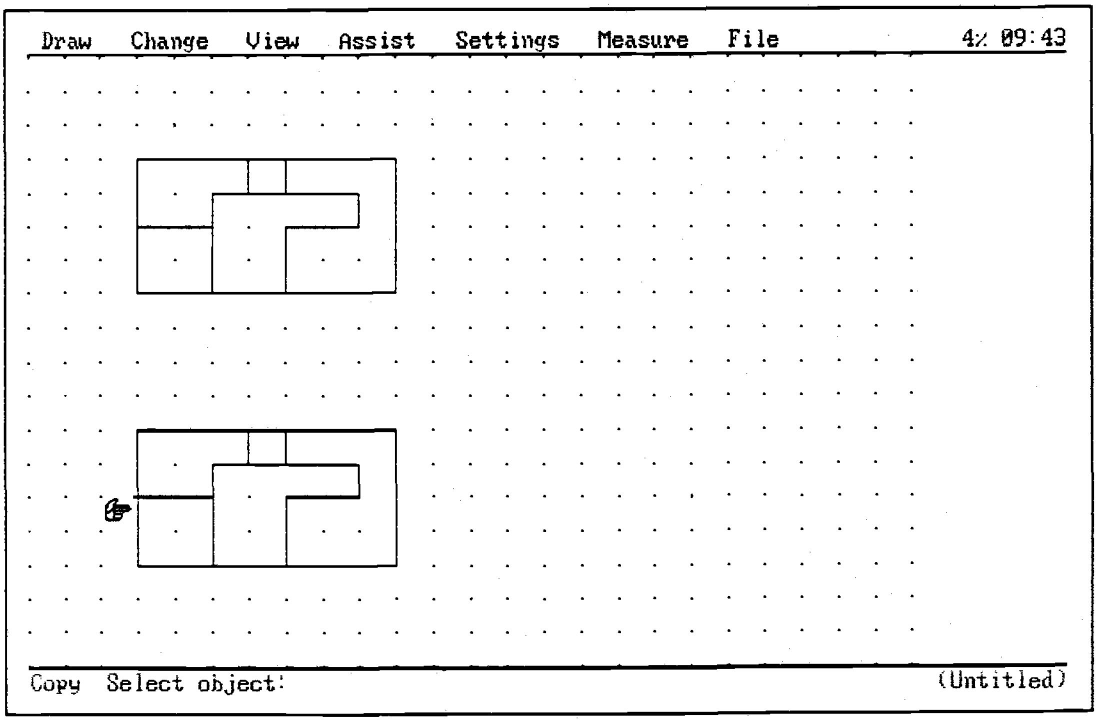
The following pages give you written instructions for each step of the project. The instructions will appear at the bottom of each picture (just like the picture below).

The pictures show you how your screen will look during each step. You should look at the picture first, then read the instructions. After reading the instructions you are to do what the picture shows and the instructions say.



Point at this piece of the puzzle and click.

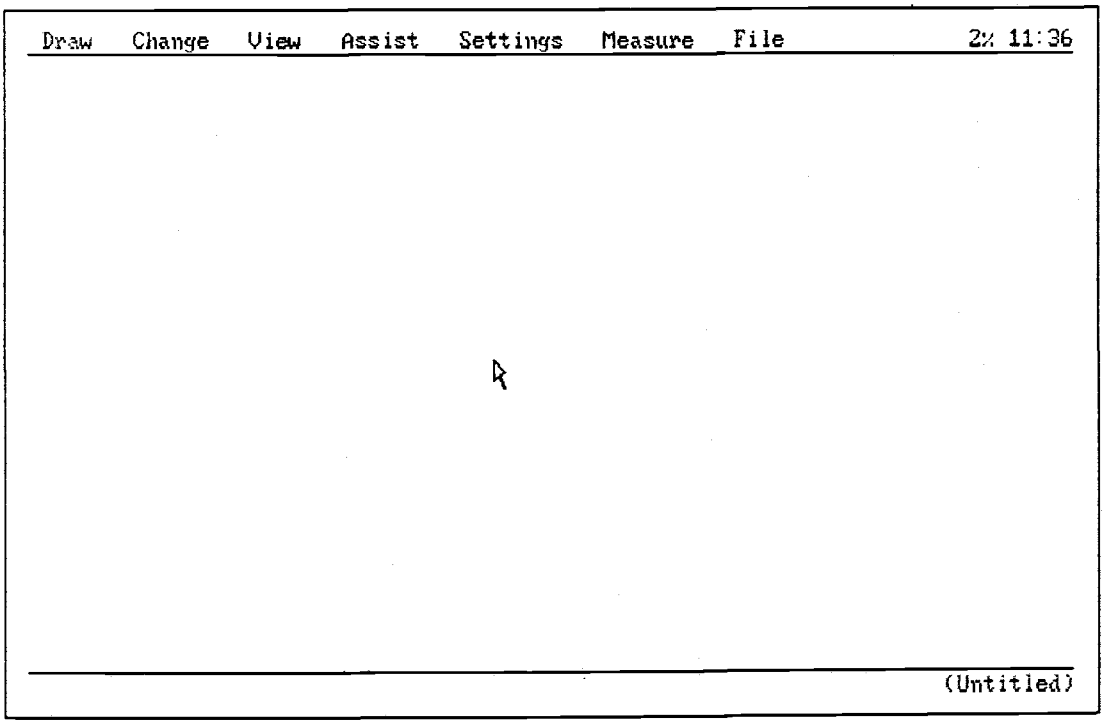
Some of the pictures are examples (just like the one below). These pictures are just to show you the different parts of the computer screen, or, how your drawing should look at that time. These picture pages are marked JUST LOOK AND READ. When you are to do something on the computer, the picture pages are marked DO THIS.



You just made an exact copy of the original puzzle.

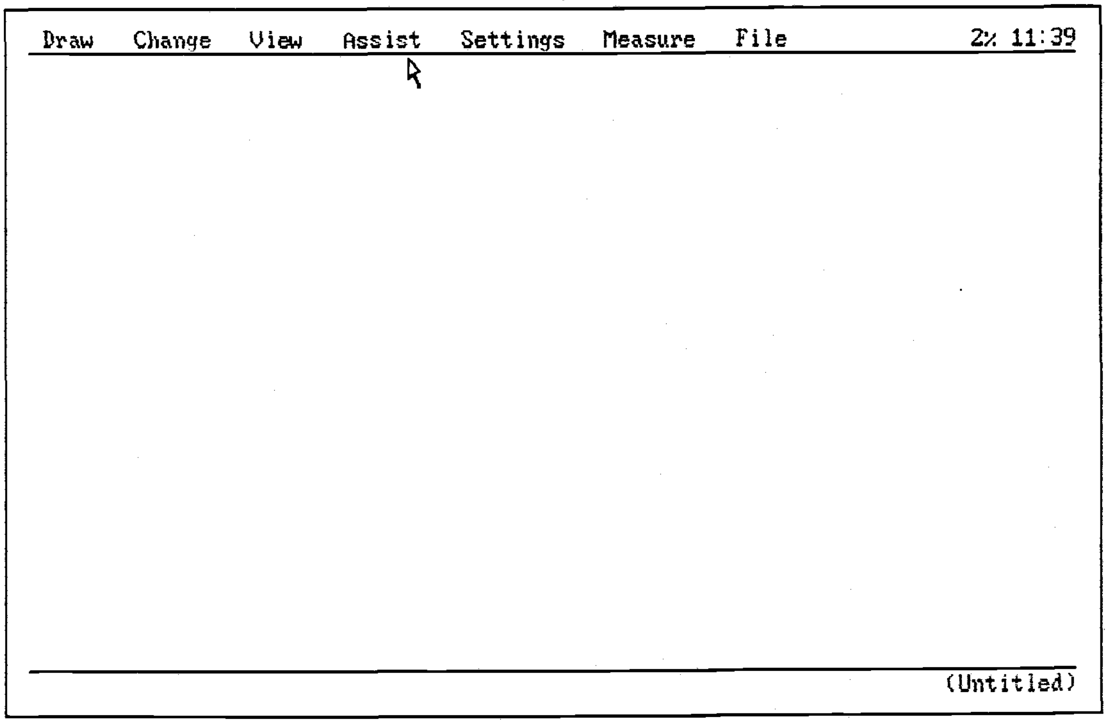
JUST LOOK AND READ

Now turn the page and follow the instructions.



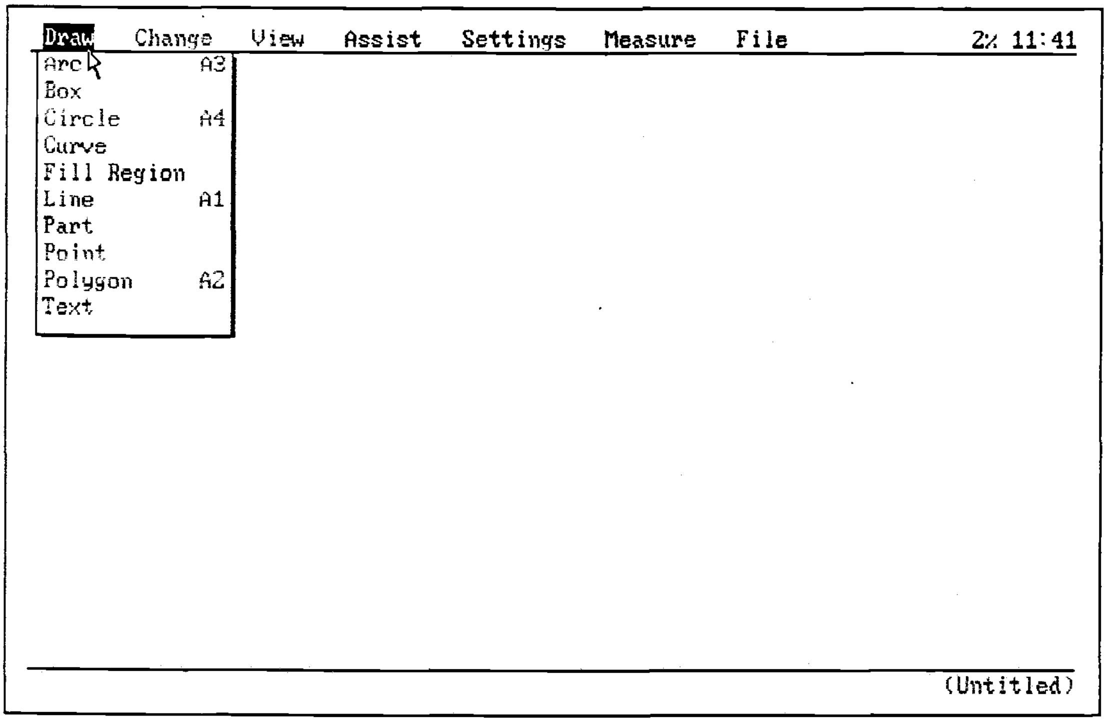
This is the AutoSketch screen. The arrow is called the cursor.

JUST LOOK AND READ



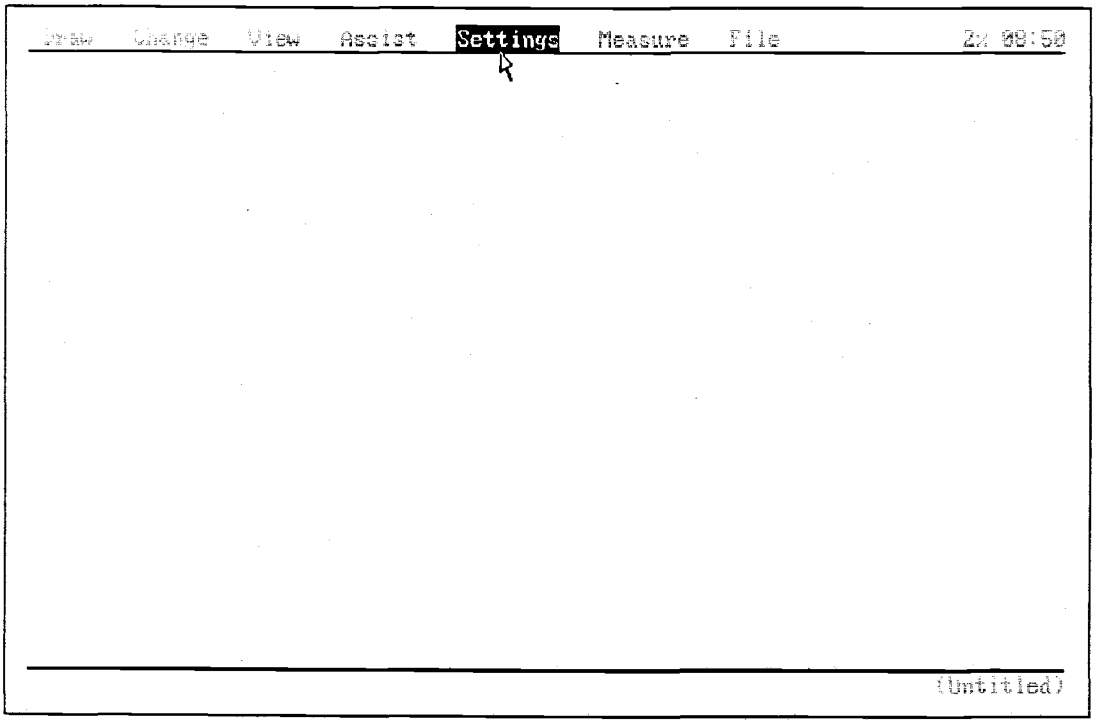
The cursor is pointing at the pull-down menu.

JUST LOOK AND READ



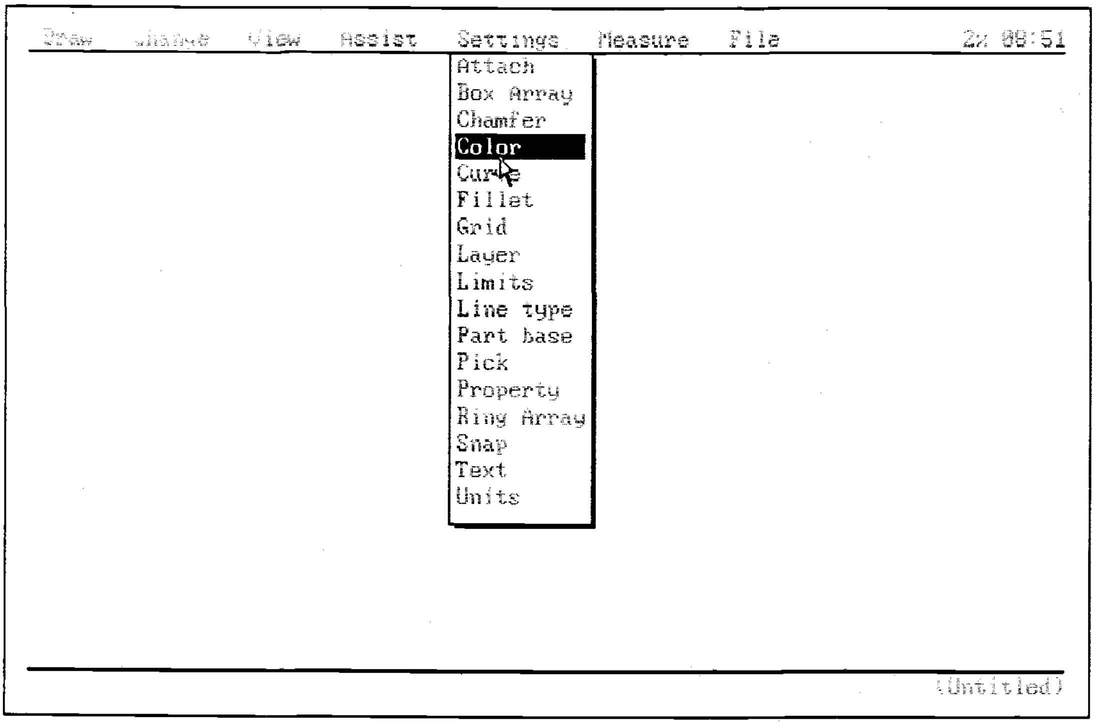
When you push the left mouse button, a menu box is pulled-down.

JUST LOOK AND READ



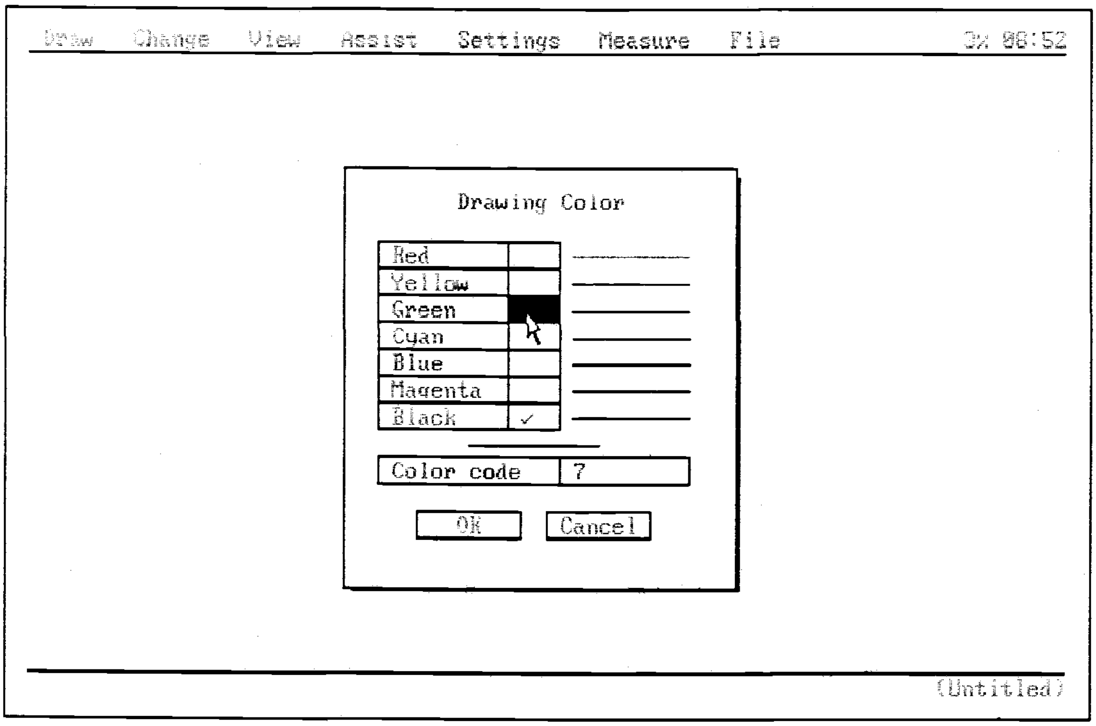
Let's use color. Select "Settings".

DO THIS



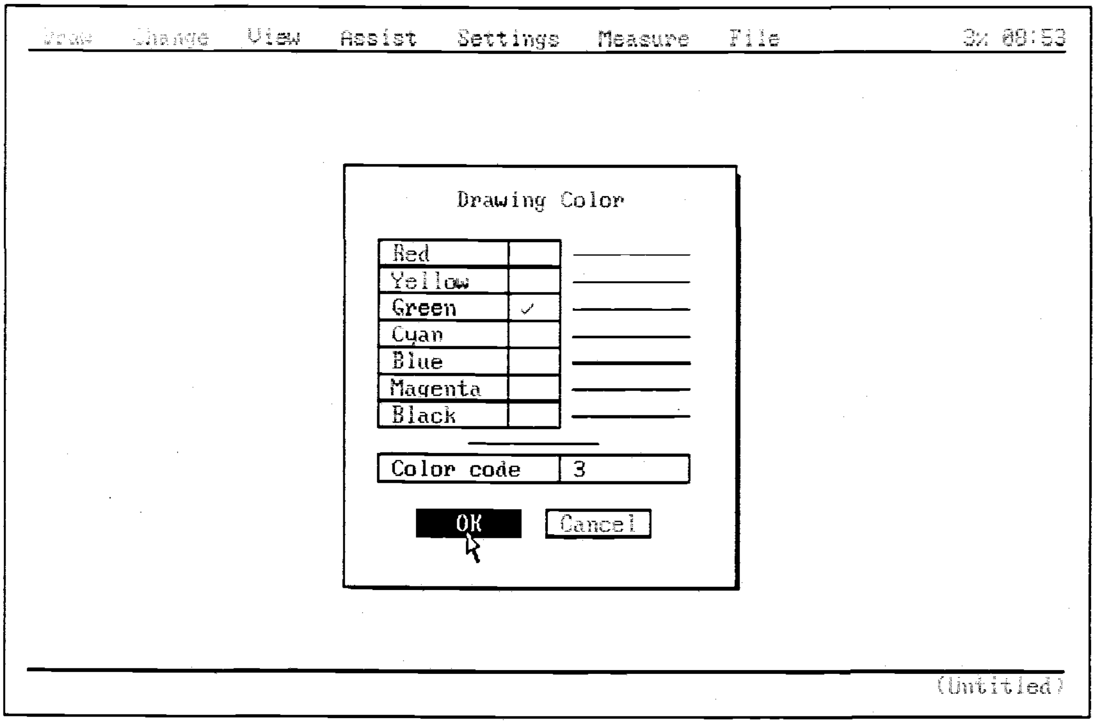
Select [Color].

DO THIS



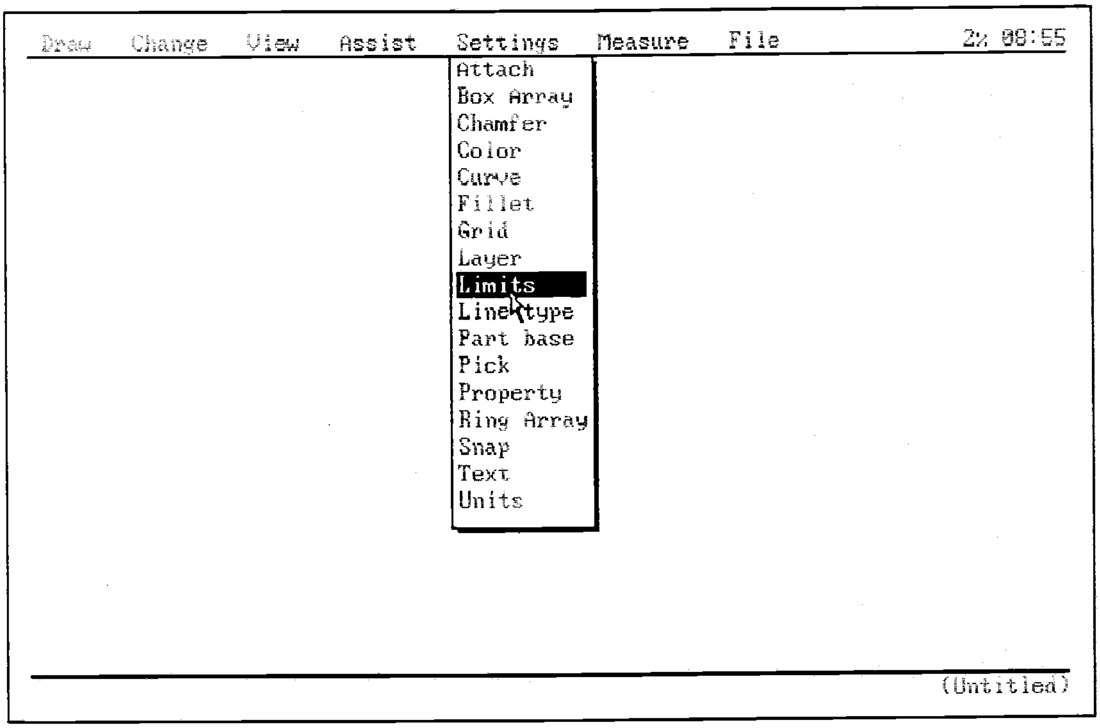
Let's draw in Green. Highlight the box next to Green, and click.

DO THIS



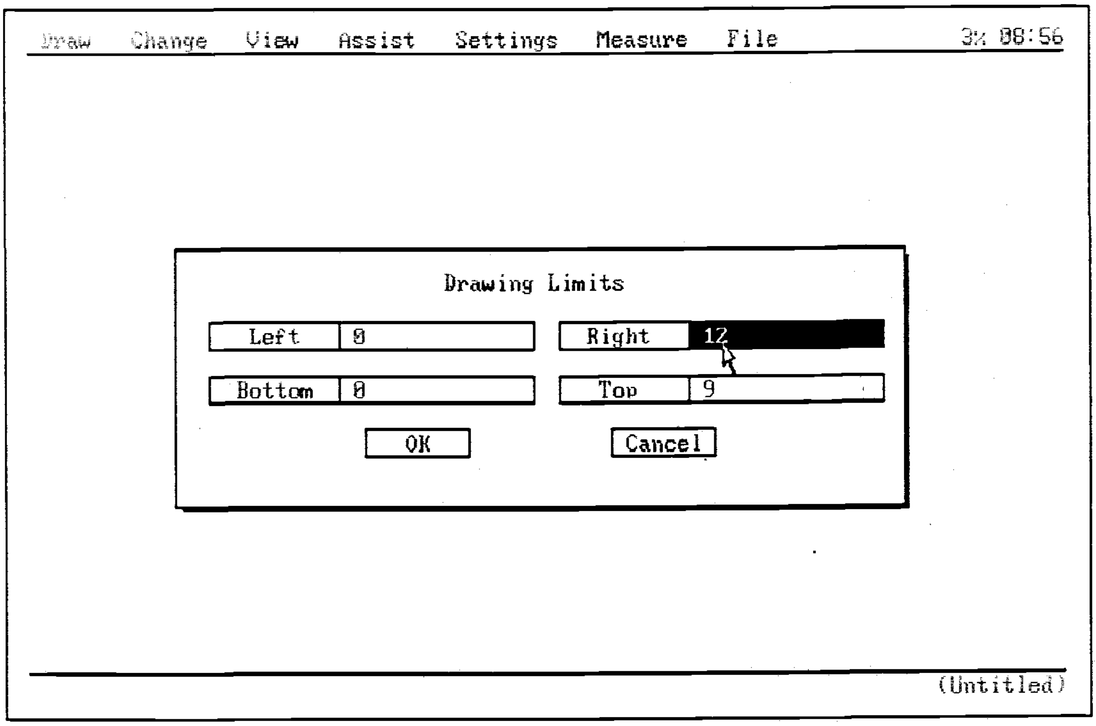
Now select [OK].

DO THIS



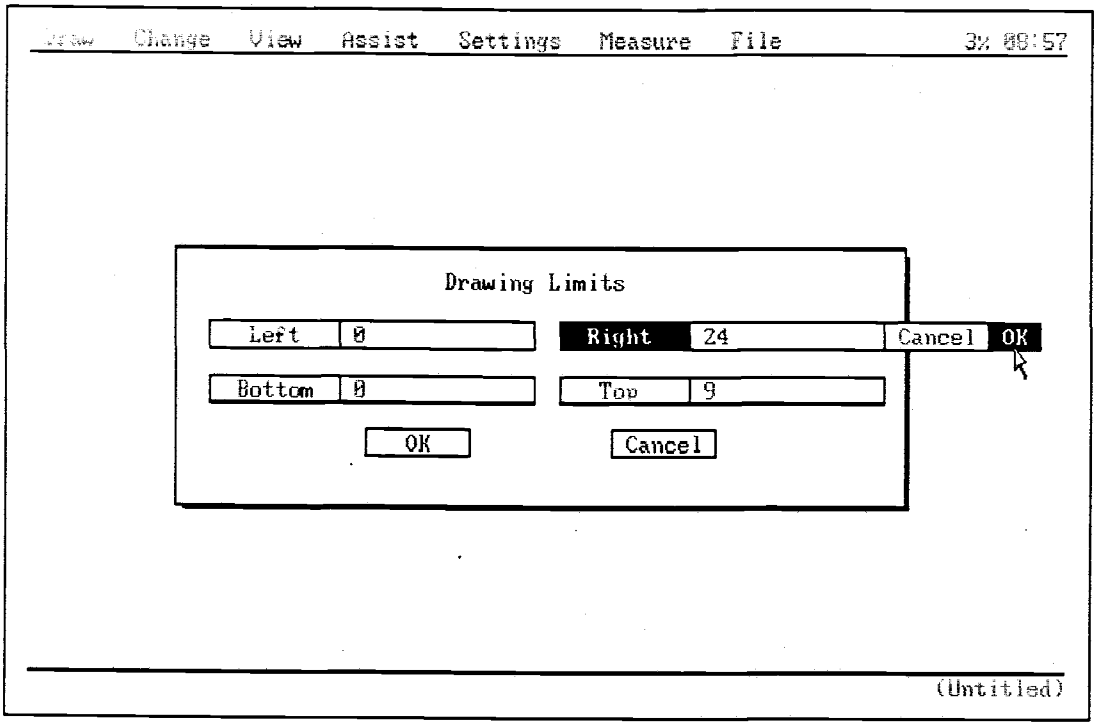
Let's make a few more settings. Select [Limits].

DO THIS



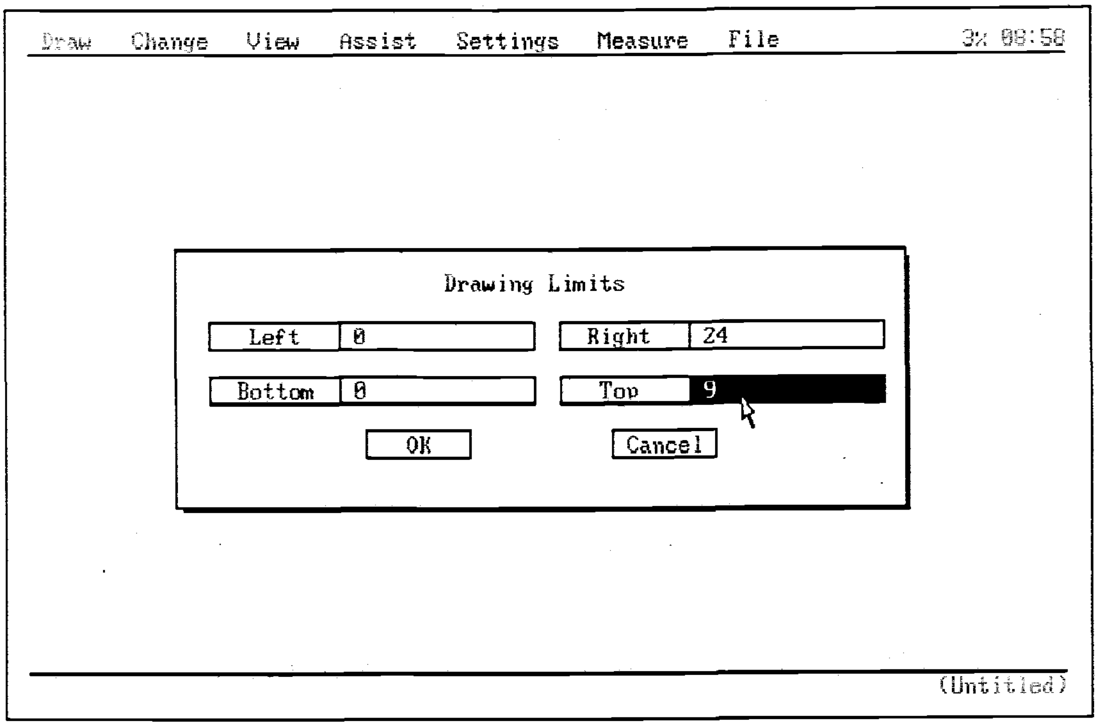
Highlight the box marked [12] and click. Now type 24.

DO THIS



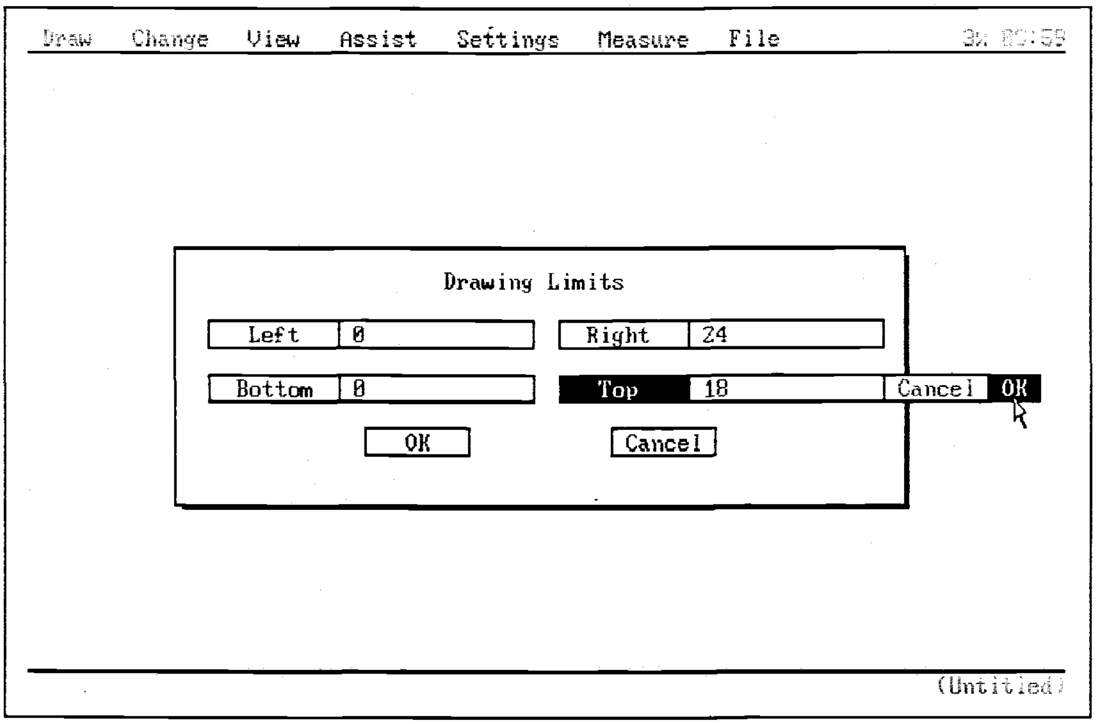
Now [OK].

DO THIS



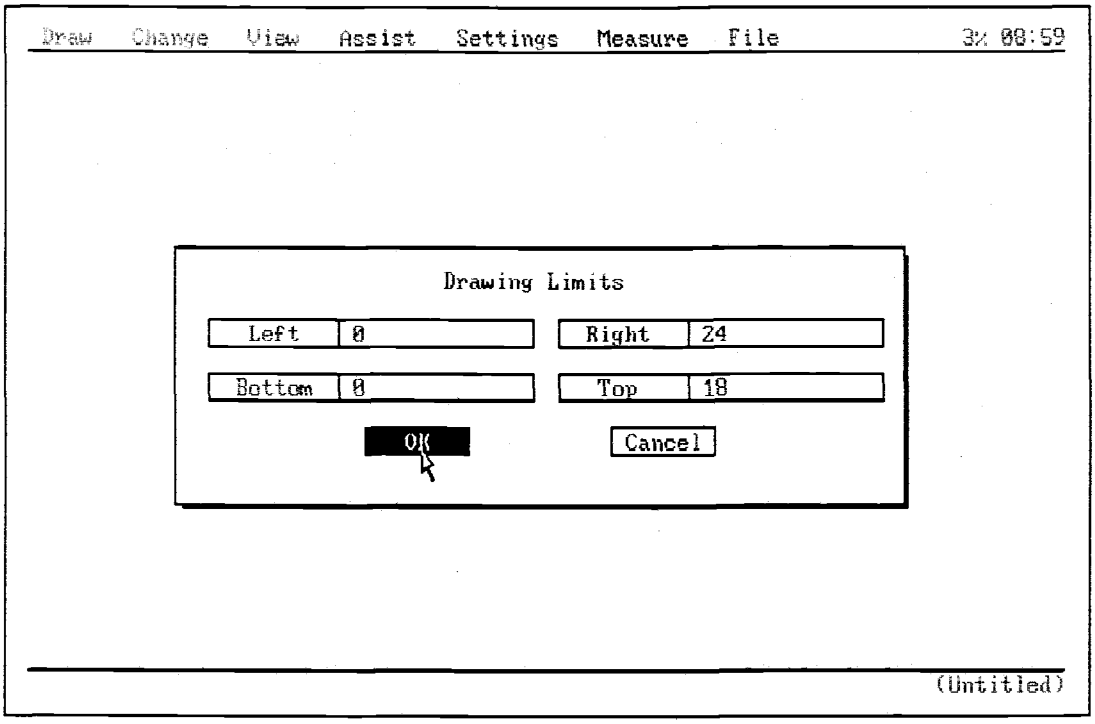
Highlight the [9] and click. Now type 18.

DO THIS



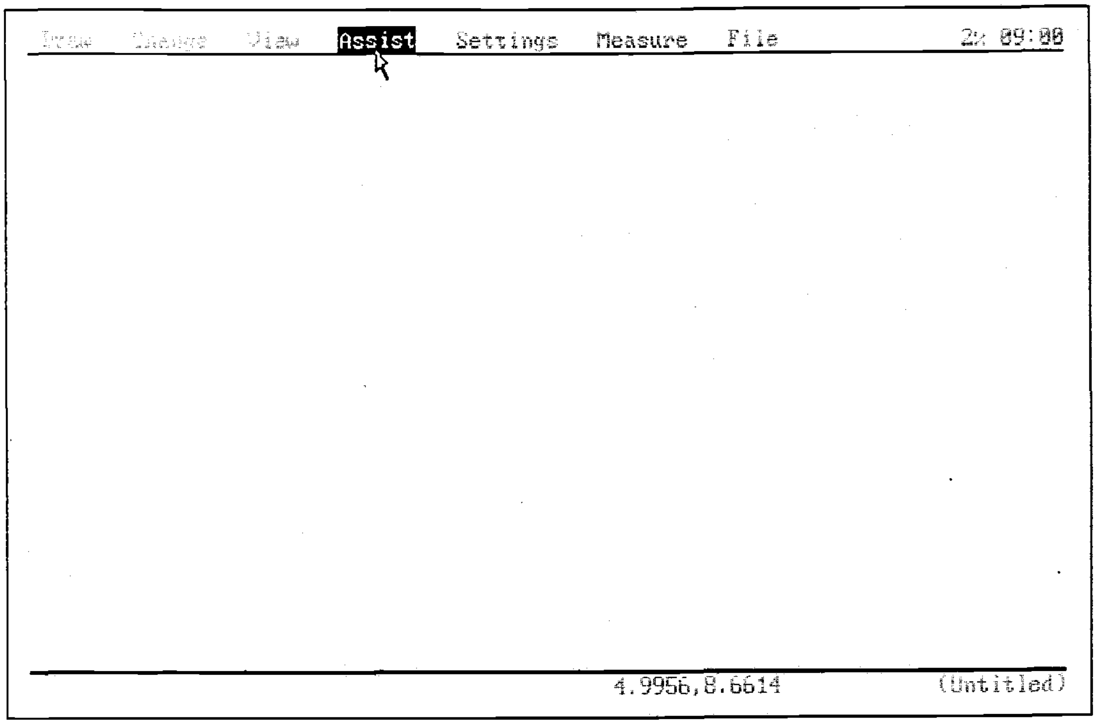
Now [OK].

DO THIS



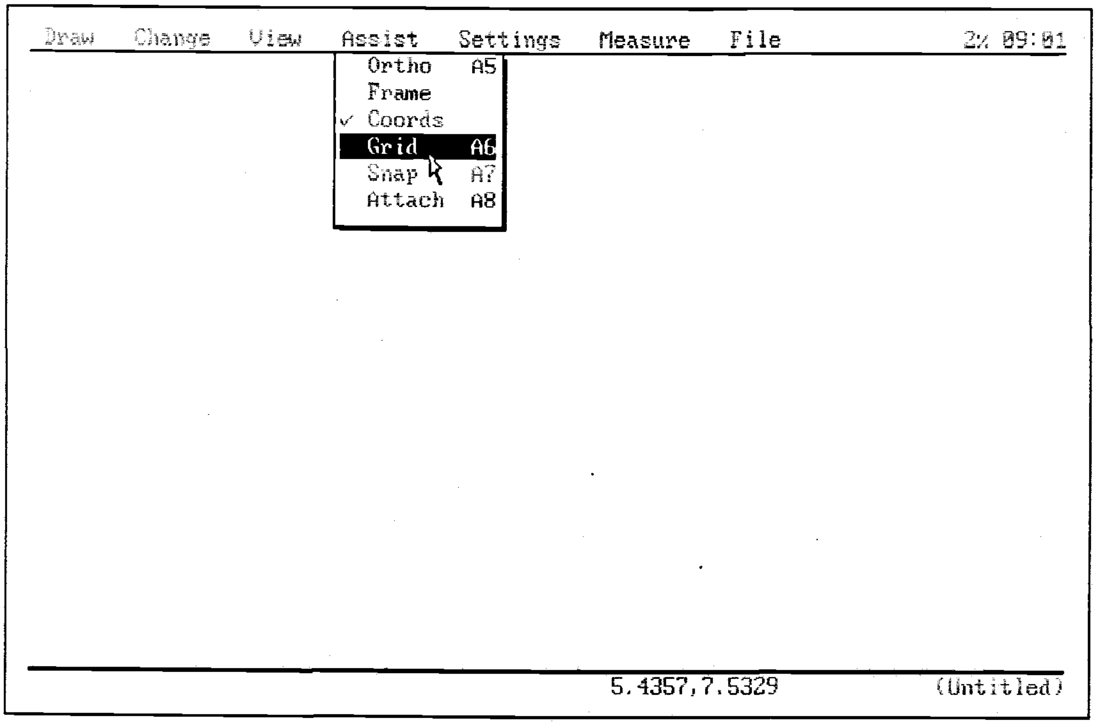
And [OK] again.

DO THIS



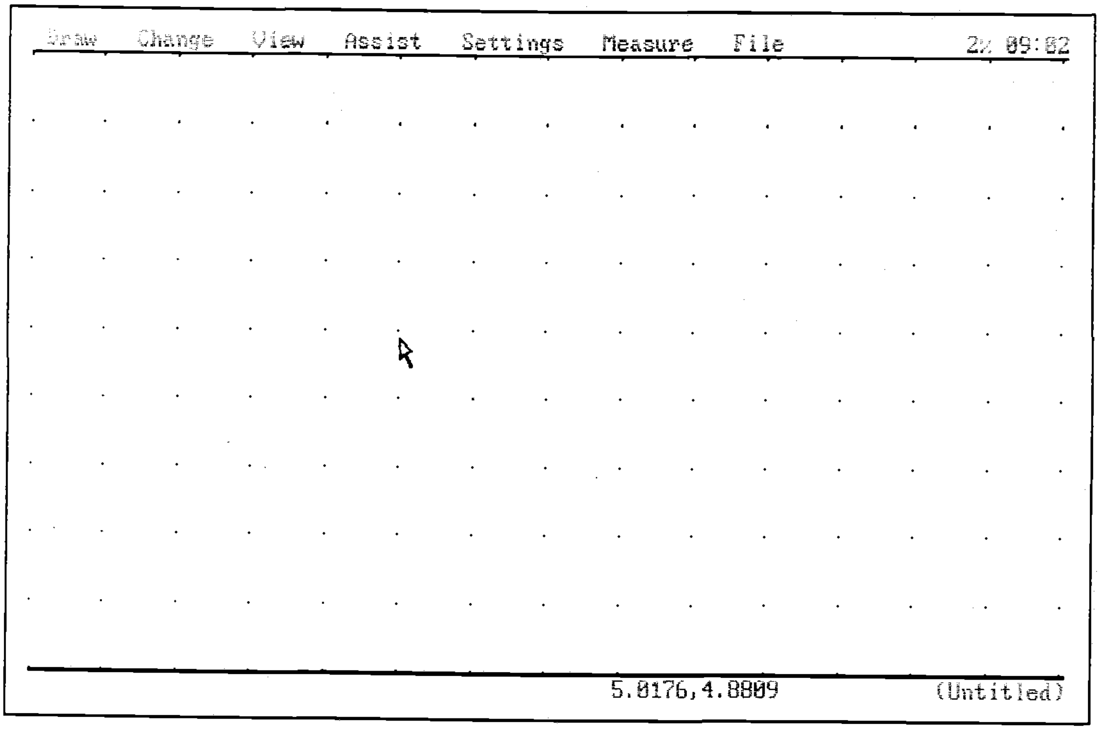
Let's set up some dots on the screen to help us. Select "Assist".

DO THIS



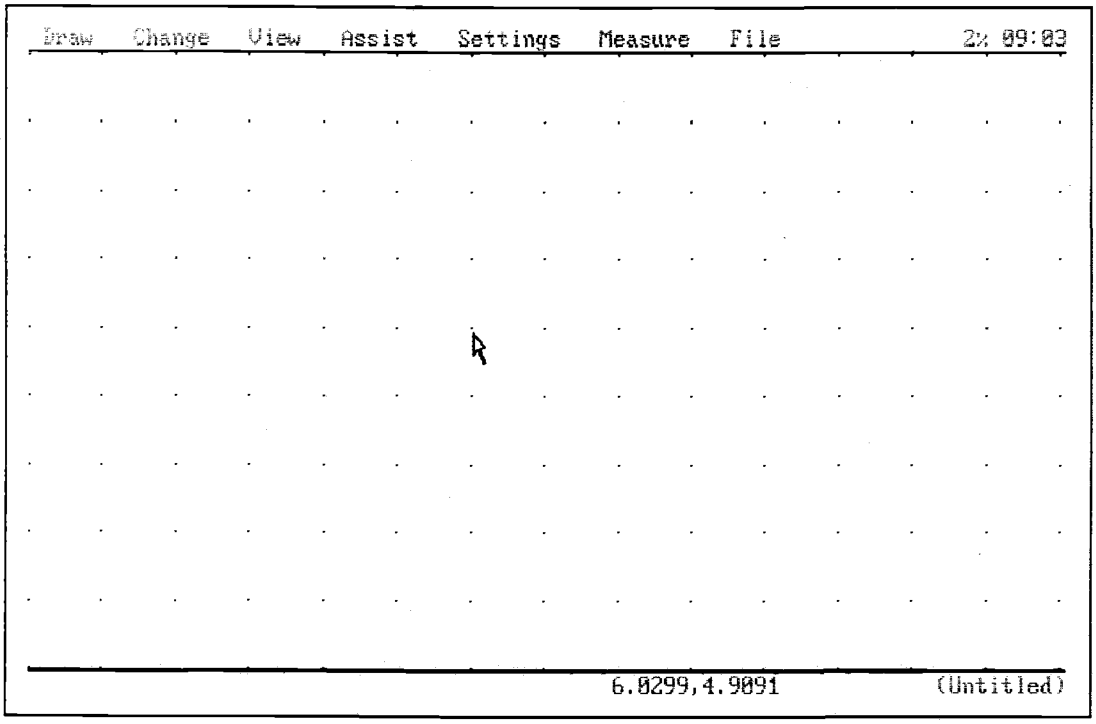
Select [Grid].

DO THIS



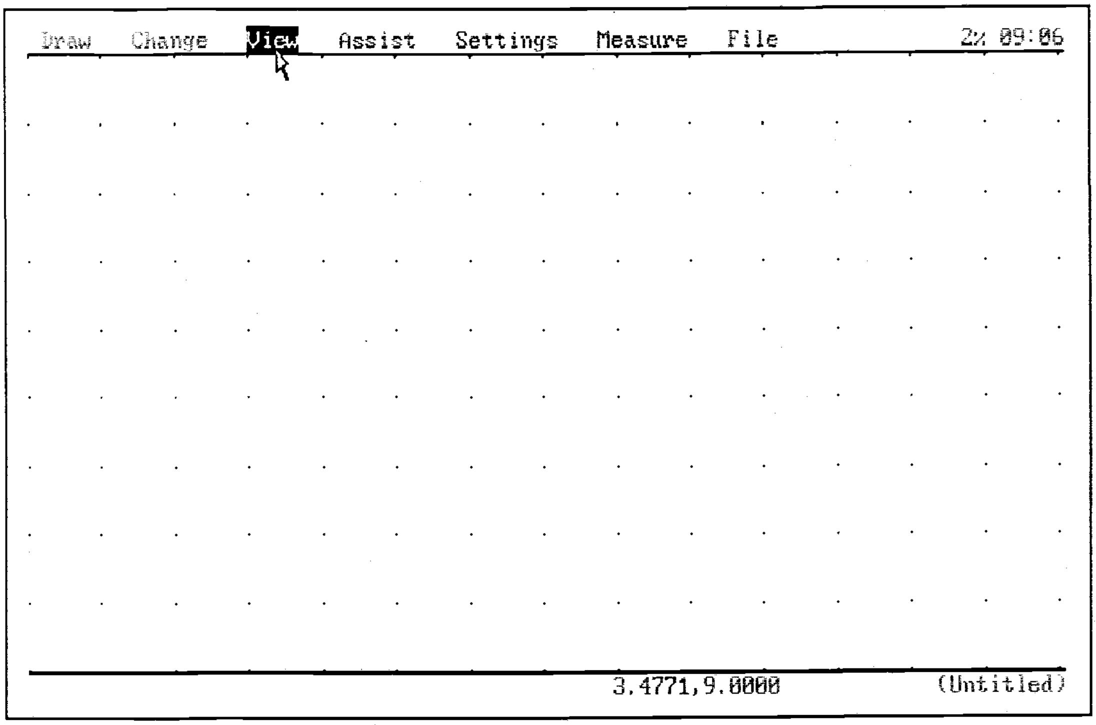
The screen should have a bunch of dots on it.

JUST LOOK AND READ



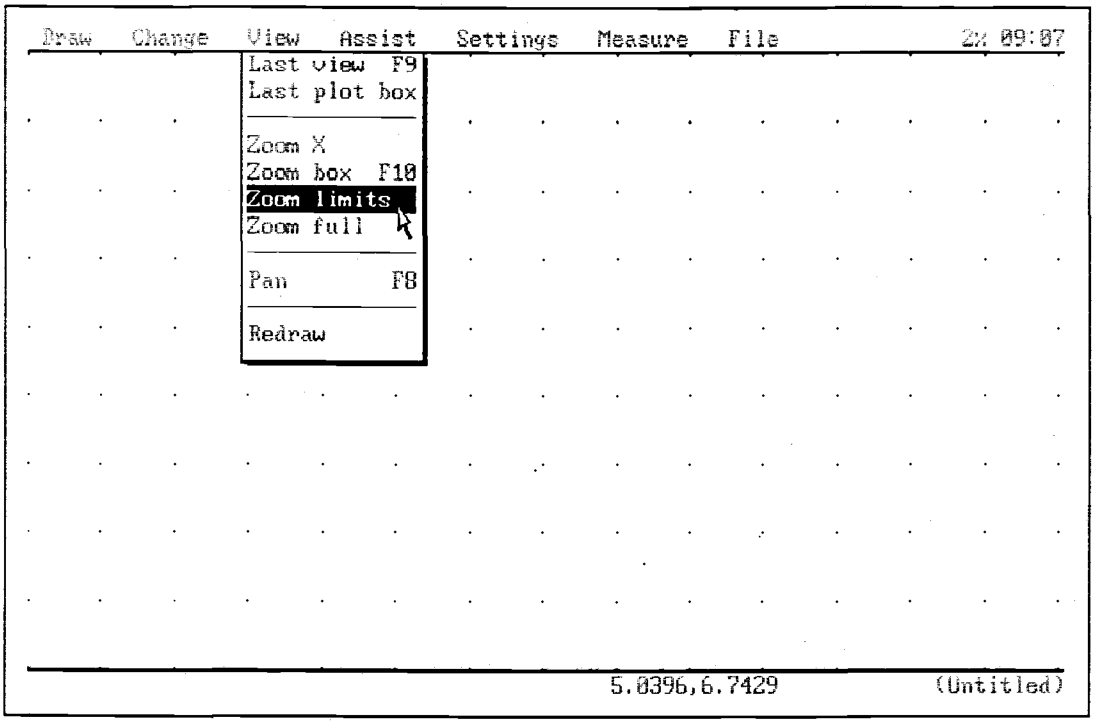
According to the computer, these dots are 1 inch apart.

JUST LOOK AND READ



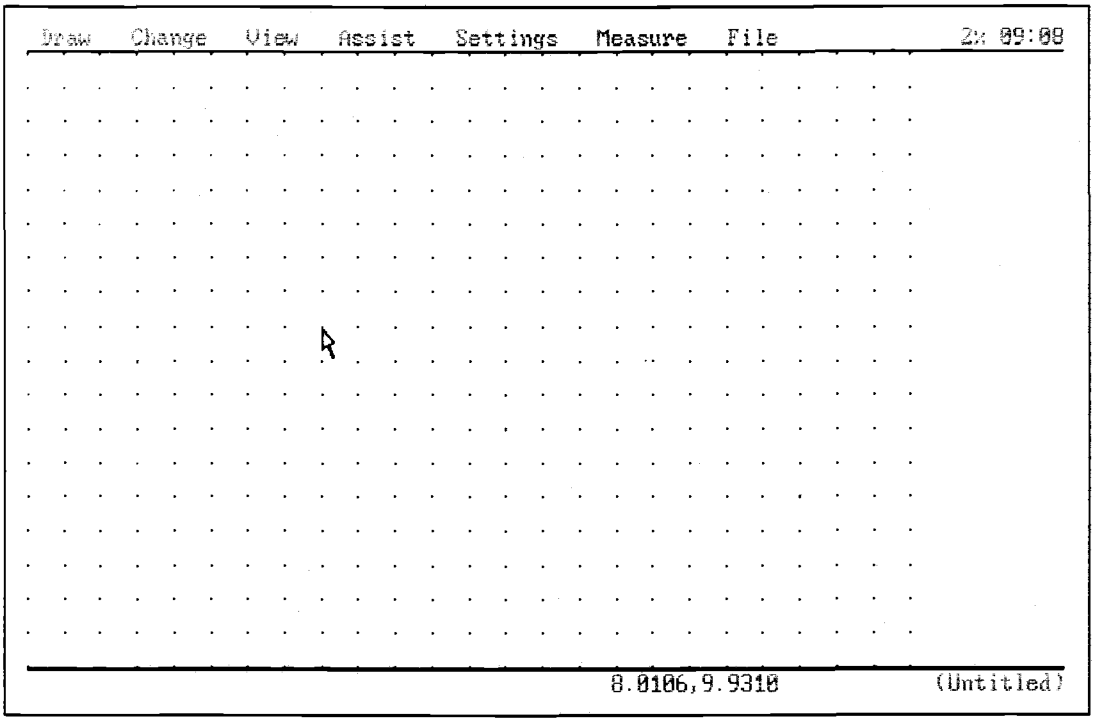
The new page is 24 inches X 18 inches. To see it all, select "View"

DO THIS



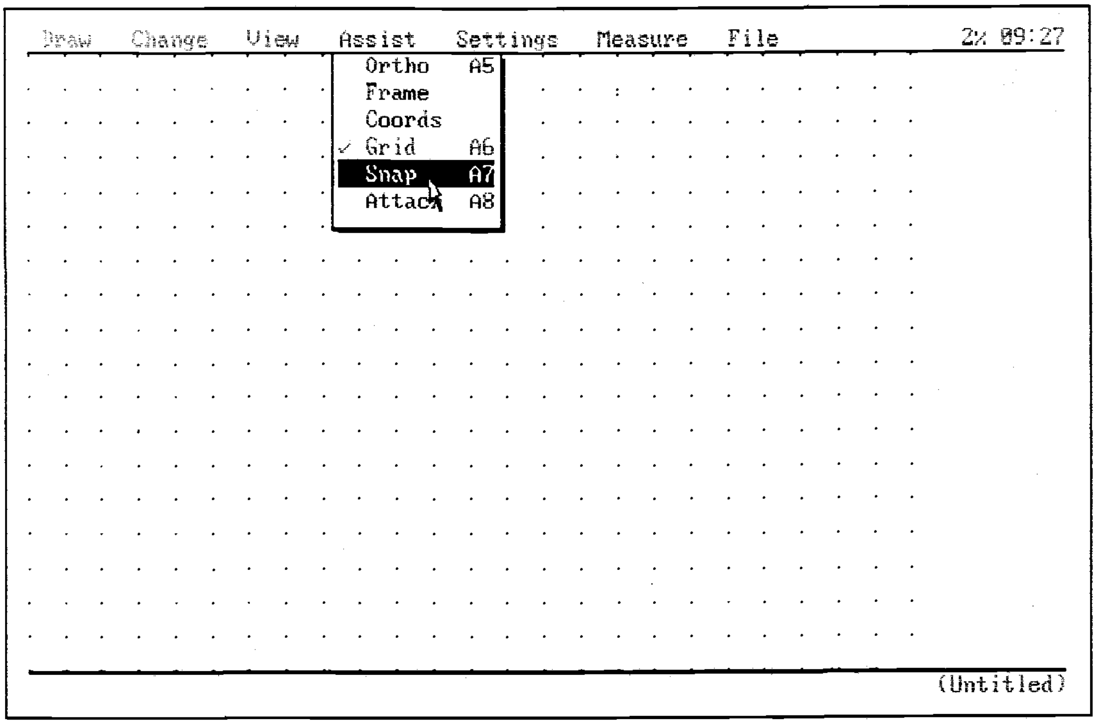
Select [Zoom limits].

DO THIS



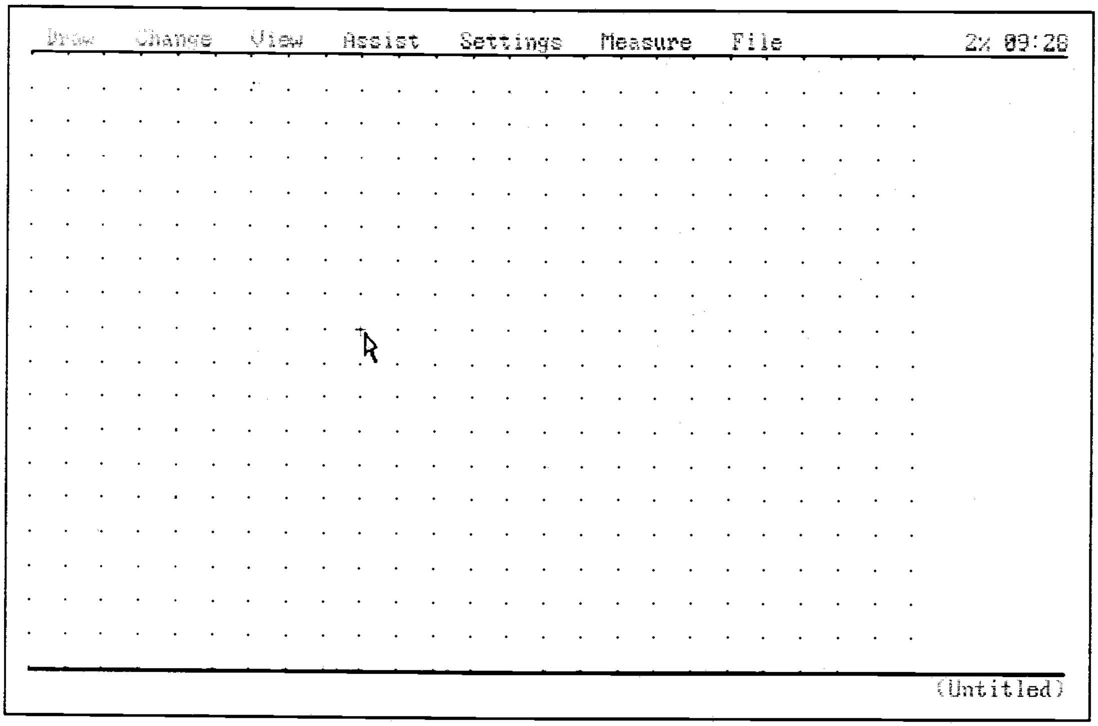
As the computer understands it, the dots are still 1 inch apart.

JUST LOOK AND READ



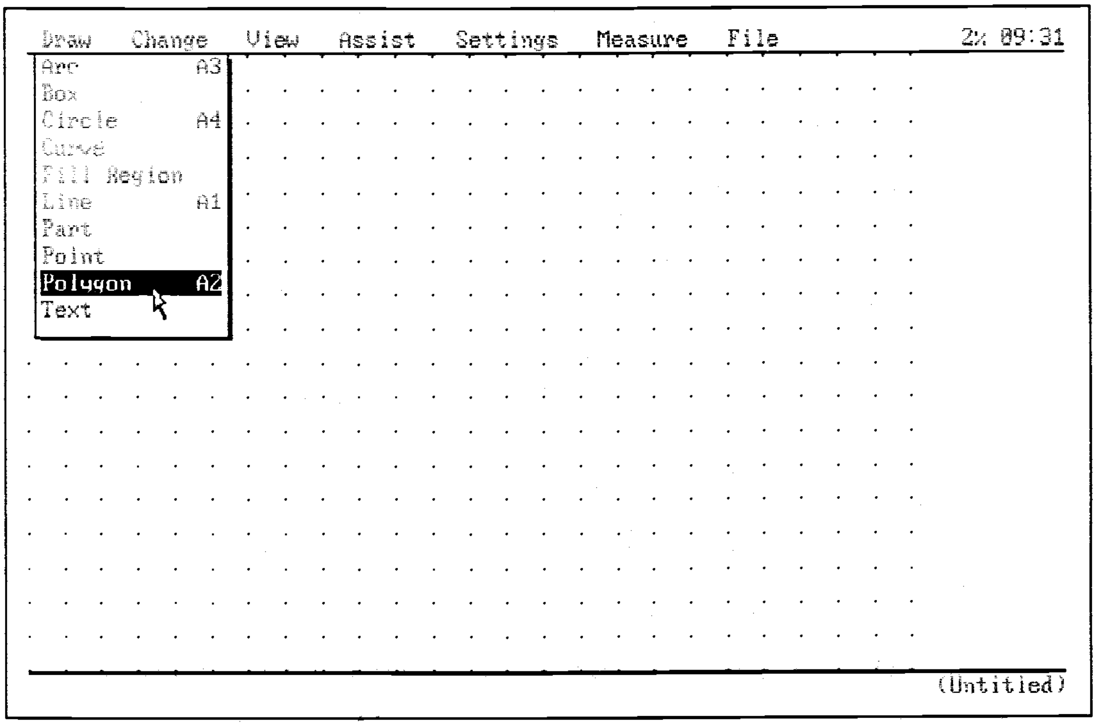
Let's set one more thing. Select [Snap A7].

DO THIS



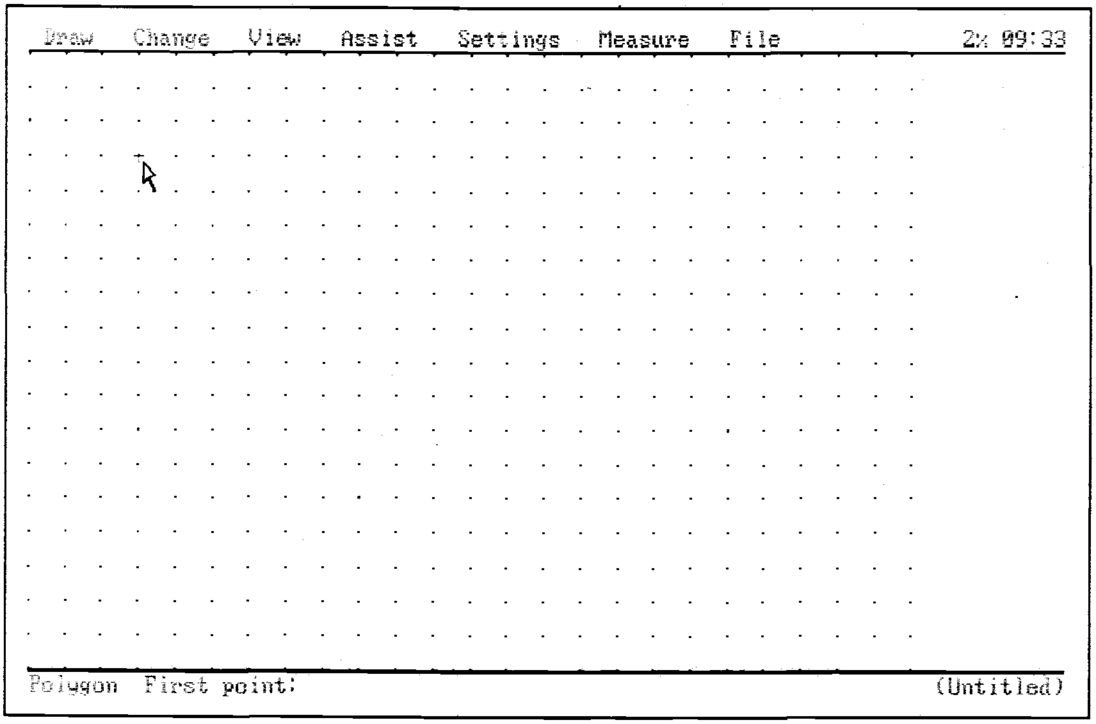
Move the cursor. You will see a cross that stops only at the dots.

DO THIS



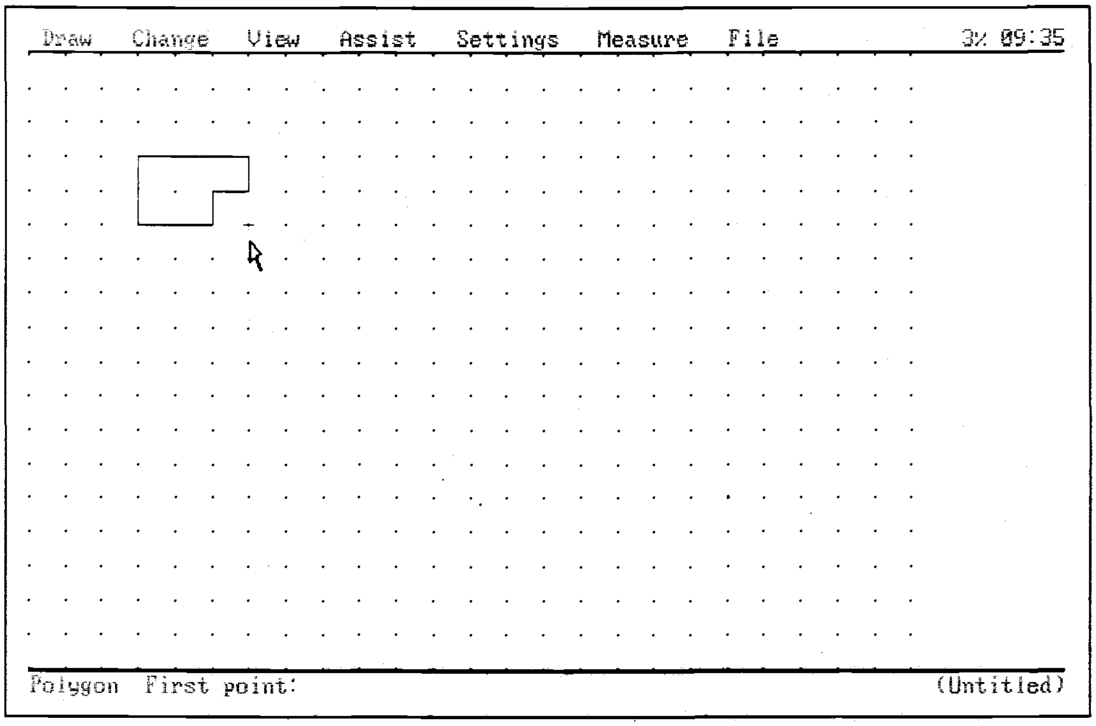
Select the [Polygon A2] command to draw the puzzle.

DO THIS



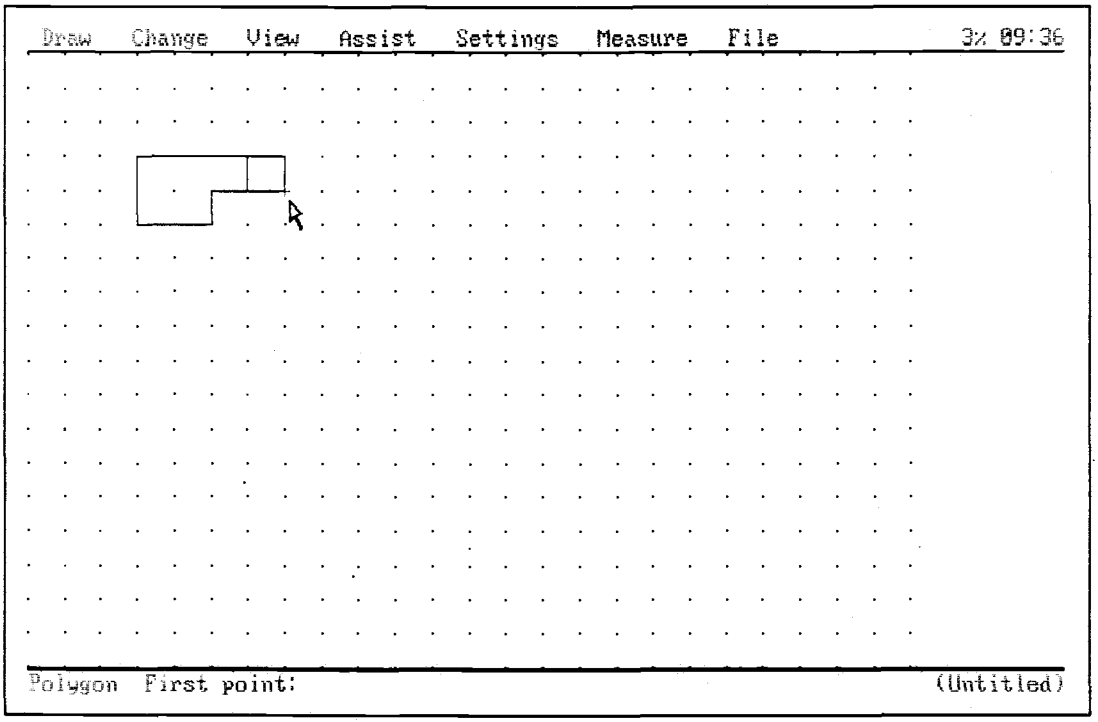
Pick the first point, over from the left and down from the top, 4 dots

DO THIS



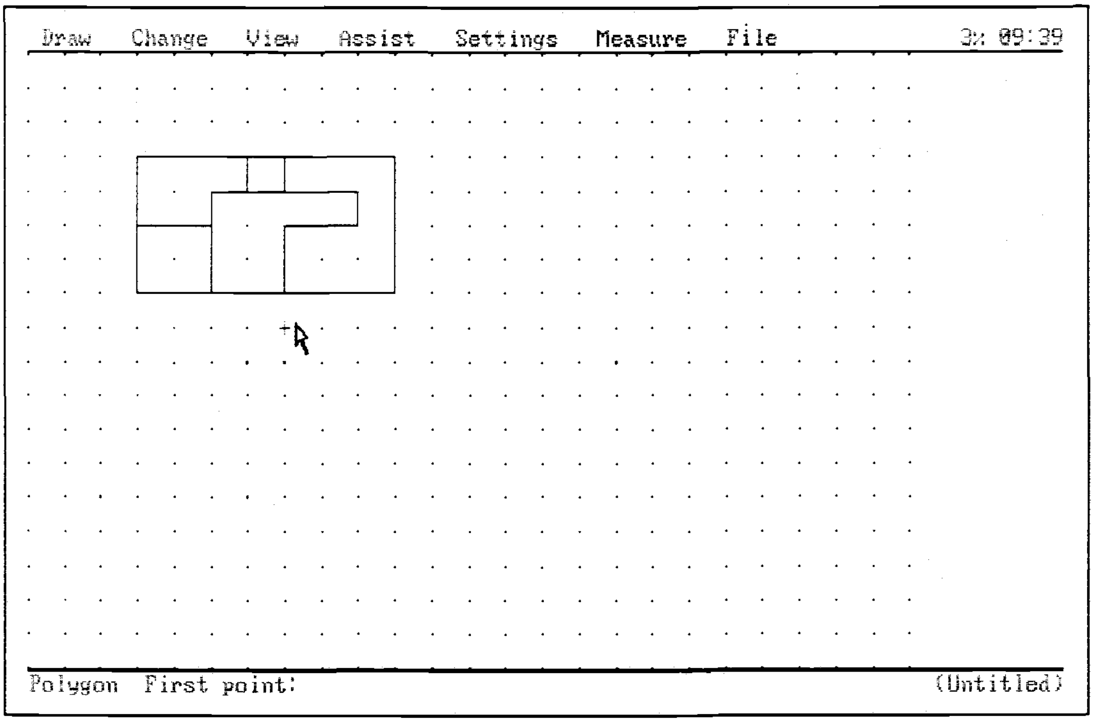
Complete the first shape just like this.

DO THIS



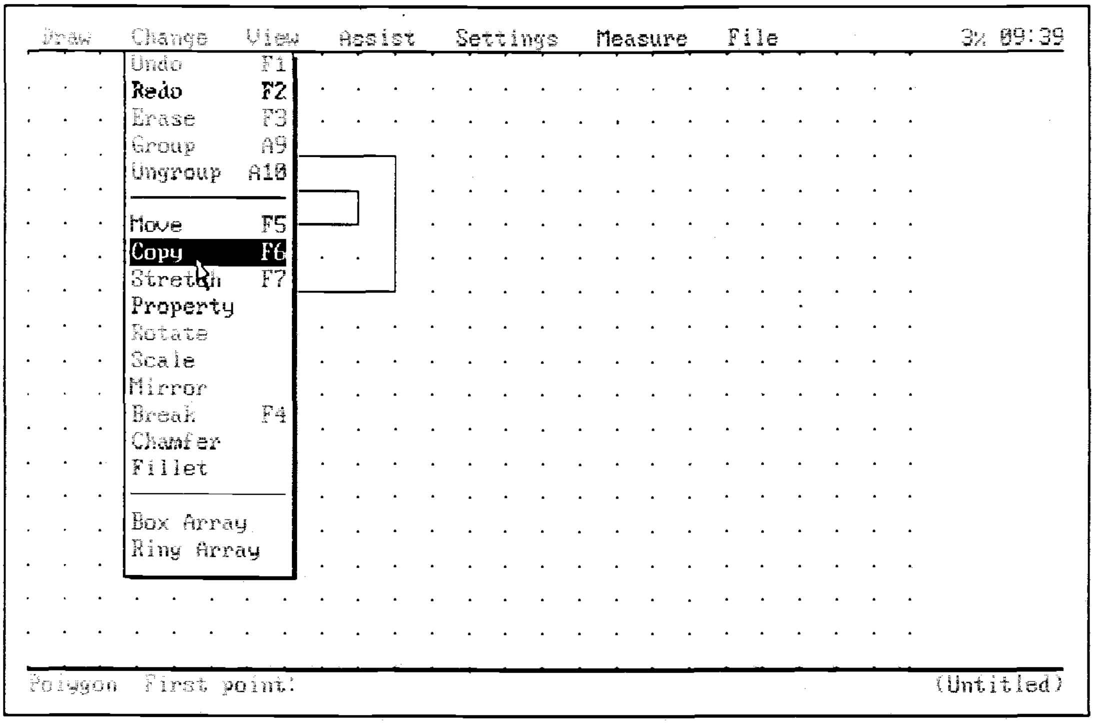
Complete the second part of the puzzle like this. Draw all 4 sides.

DO THIS



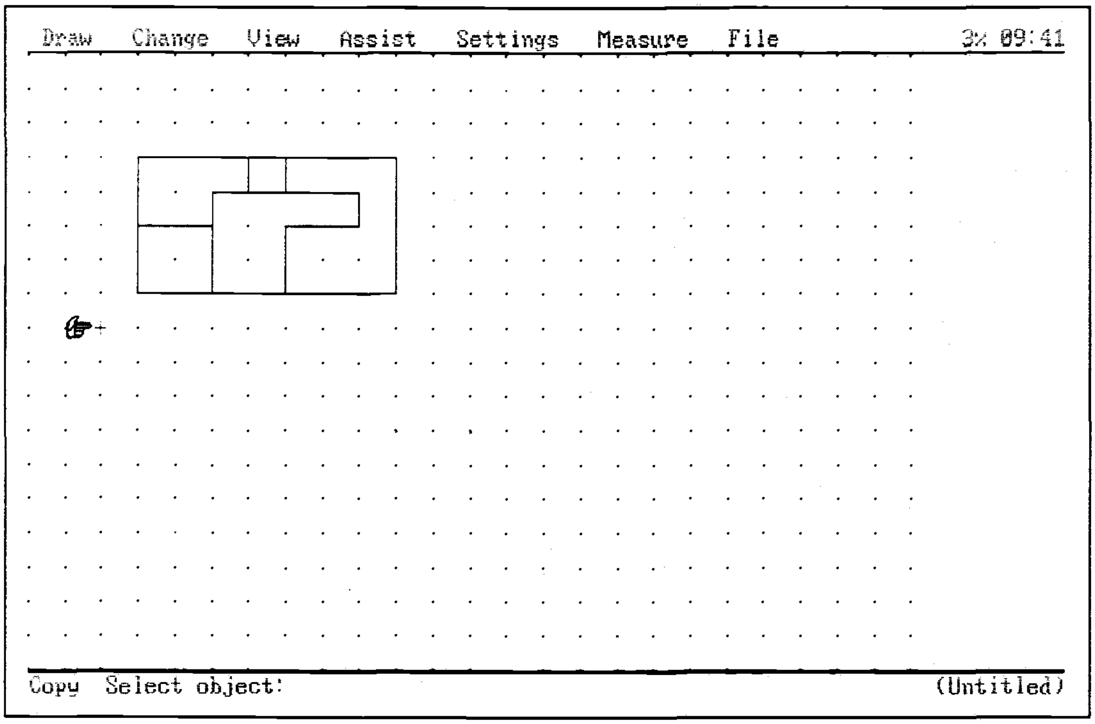
This is the completed puzzle.

DO THIS



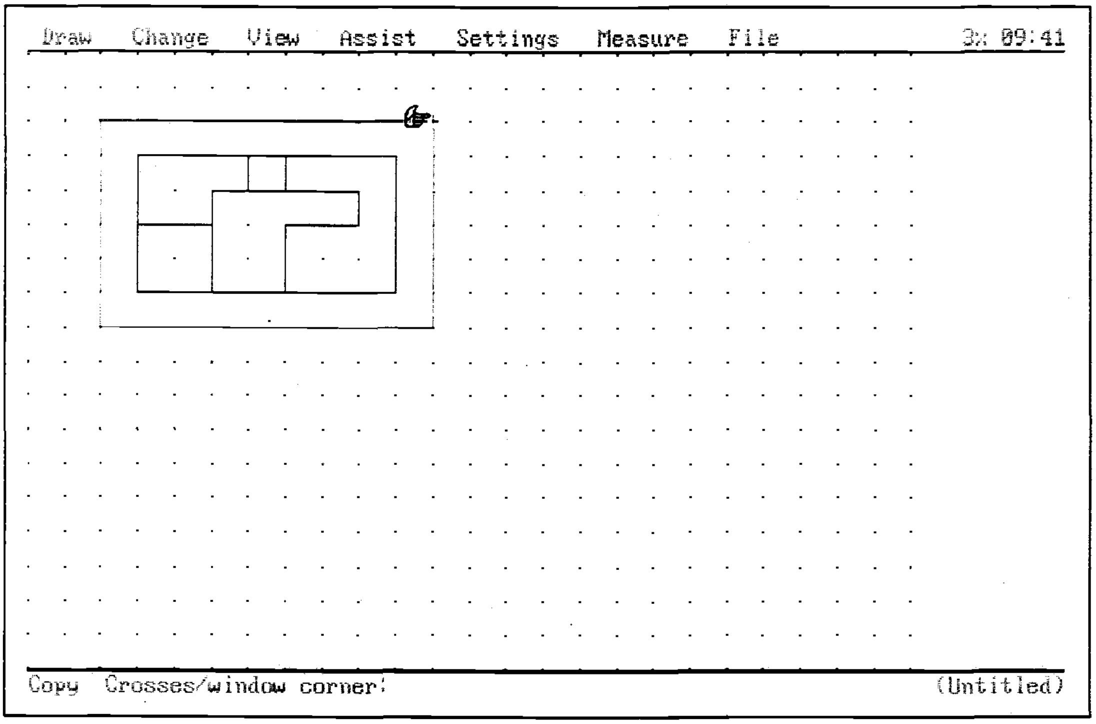
Let's make a copy of the puzzle. Select [Copy F6].

DO THIS



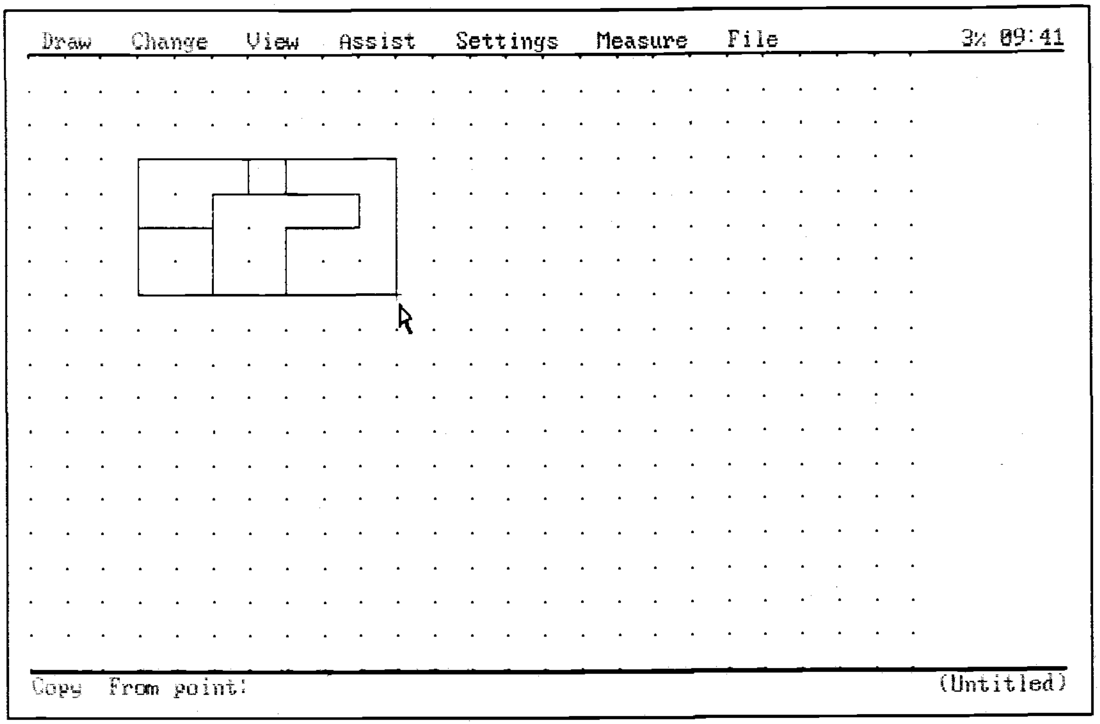
Point the finger here and click.

DO THIS



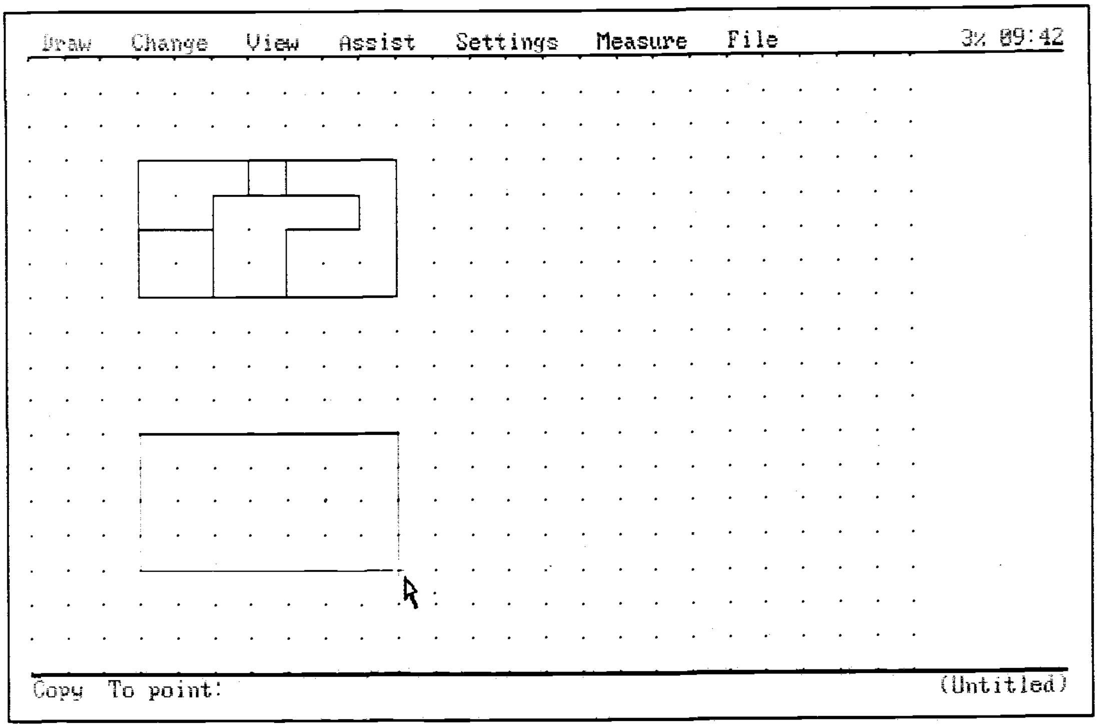
Now point the finger here and click.

DO THIS



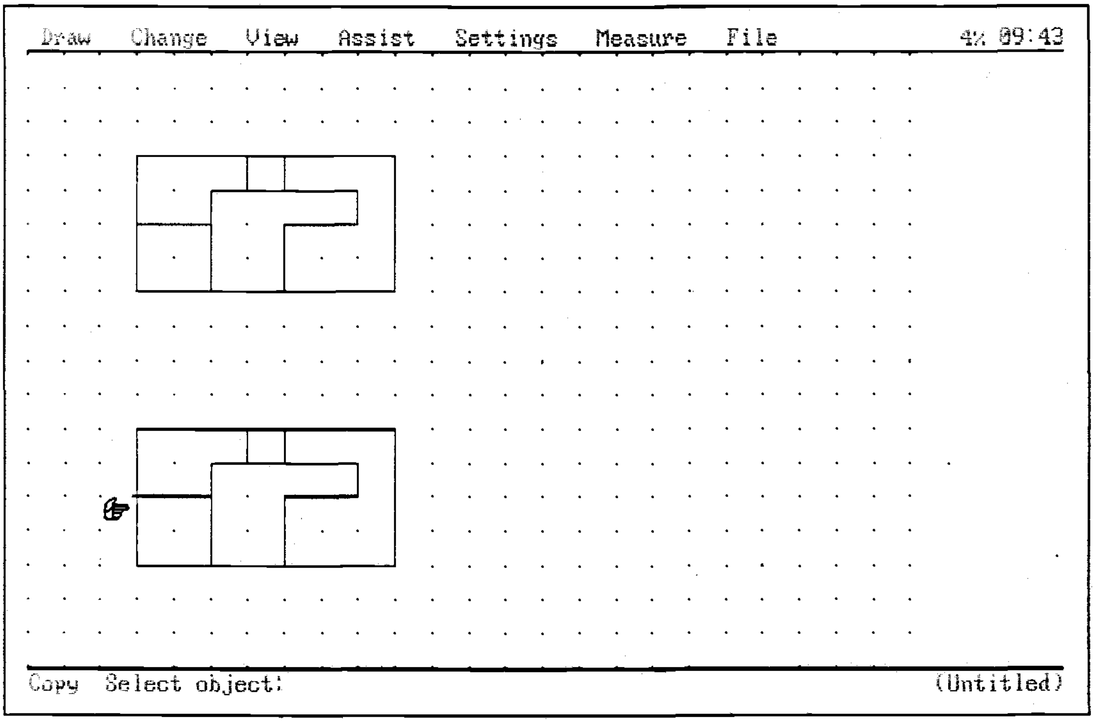
Pick this point to copy from.

DO THIS



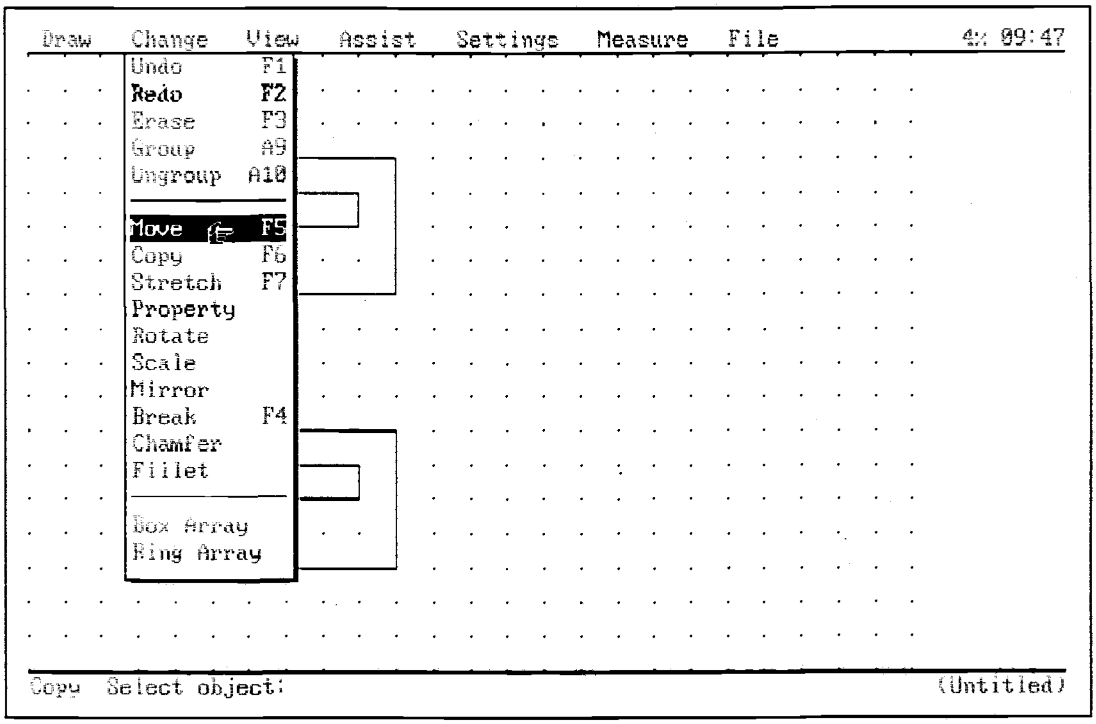
Pick this point to move your copy to.

DO THIS



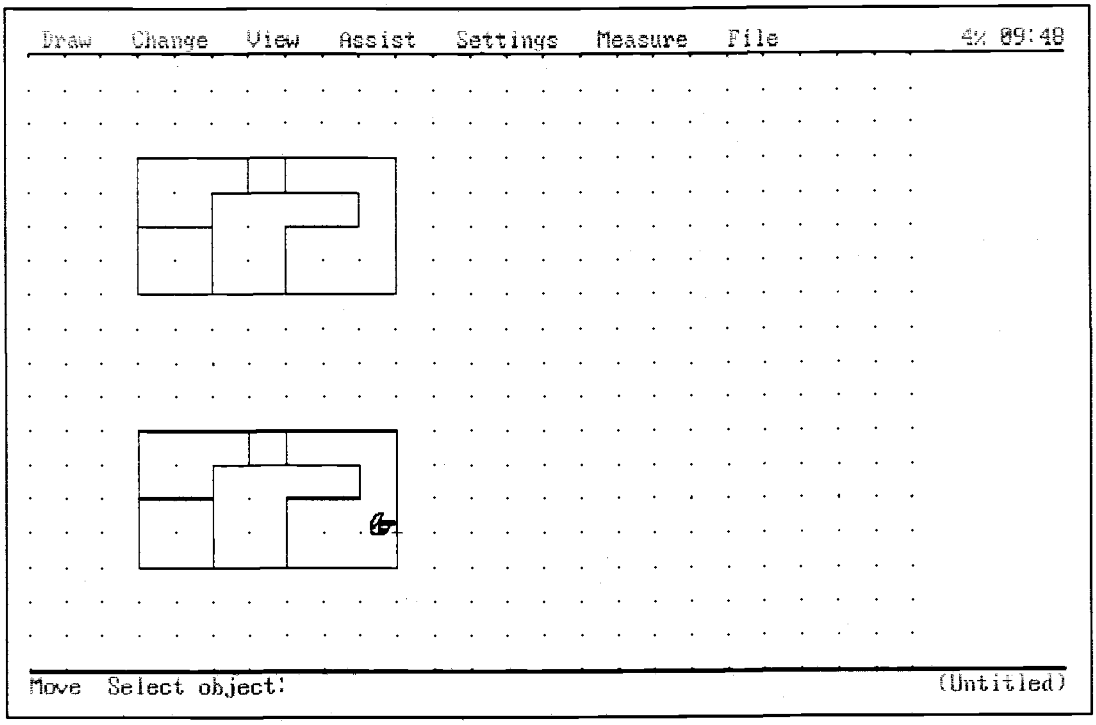
You just made an exact copy of the original puzzle.

JUST LOOK AND READ



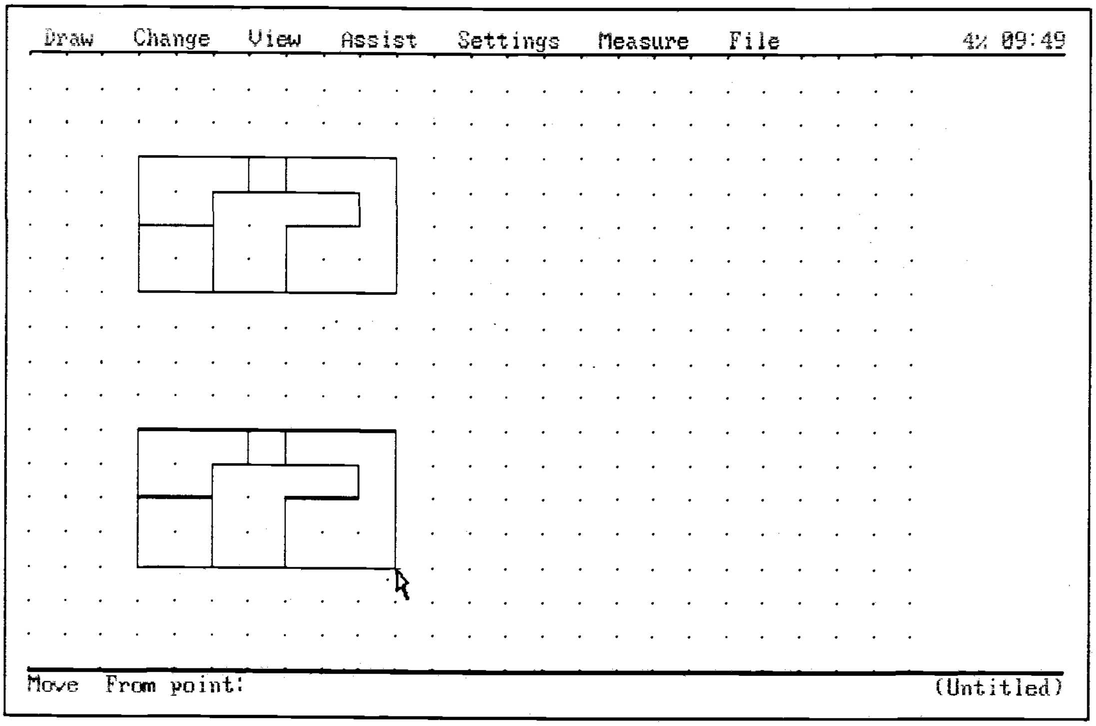
Now, let's take the copy apart. Select [Move F5].

DO THIS



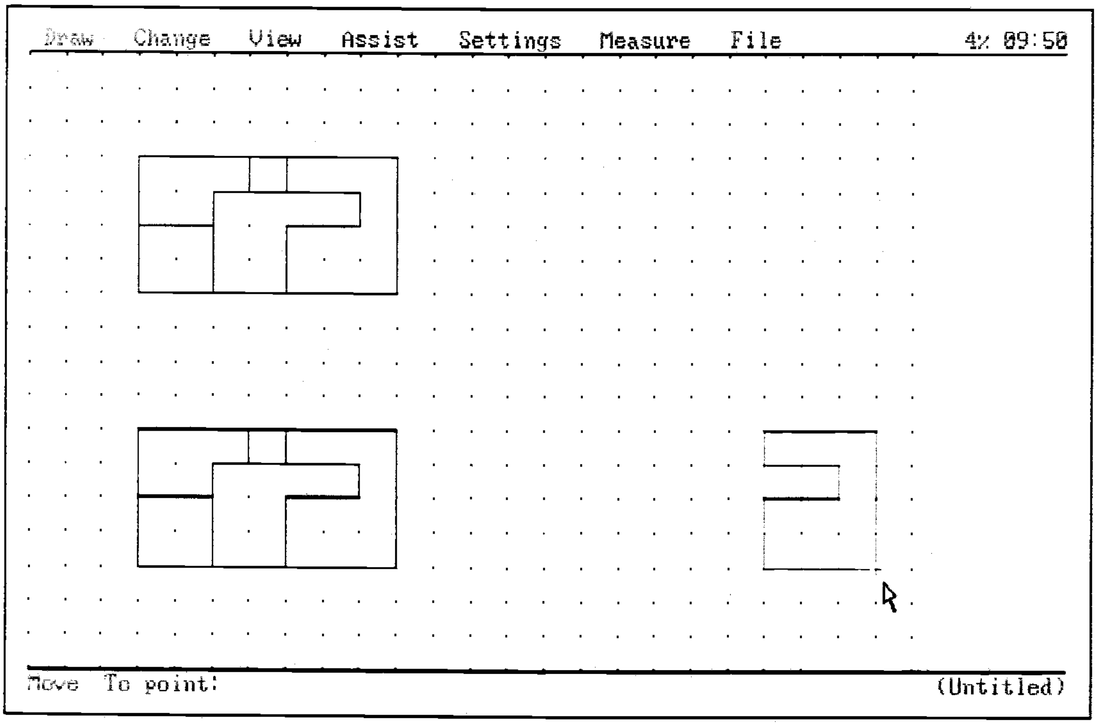
Point at this piece of the puzzle and click.

DO THIS



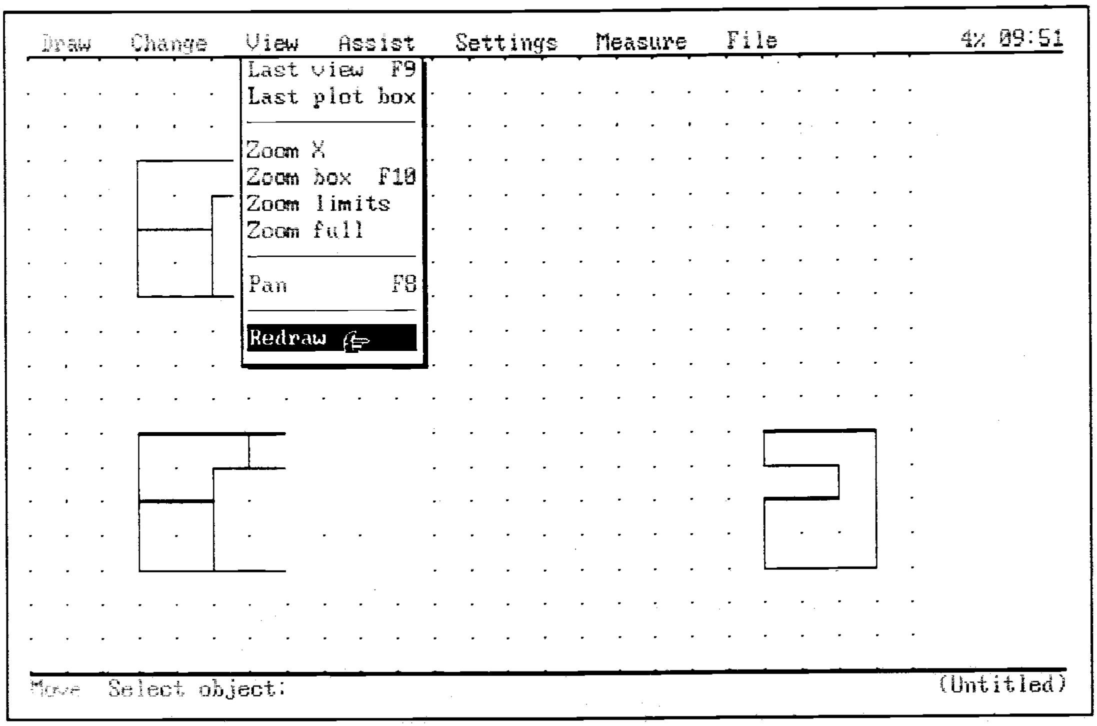
Point at this point to move from and click.

DO THIS



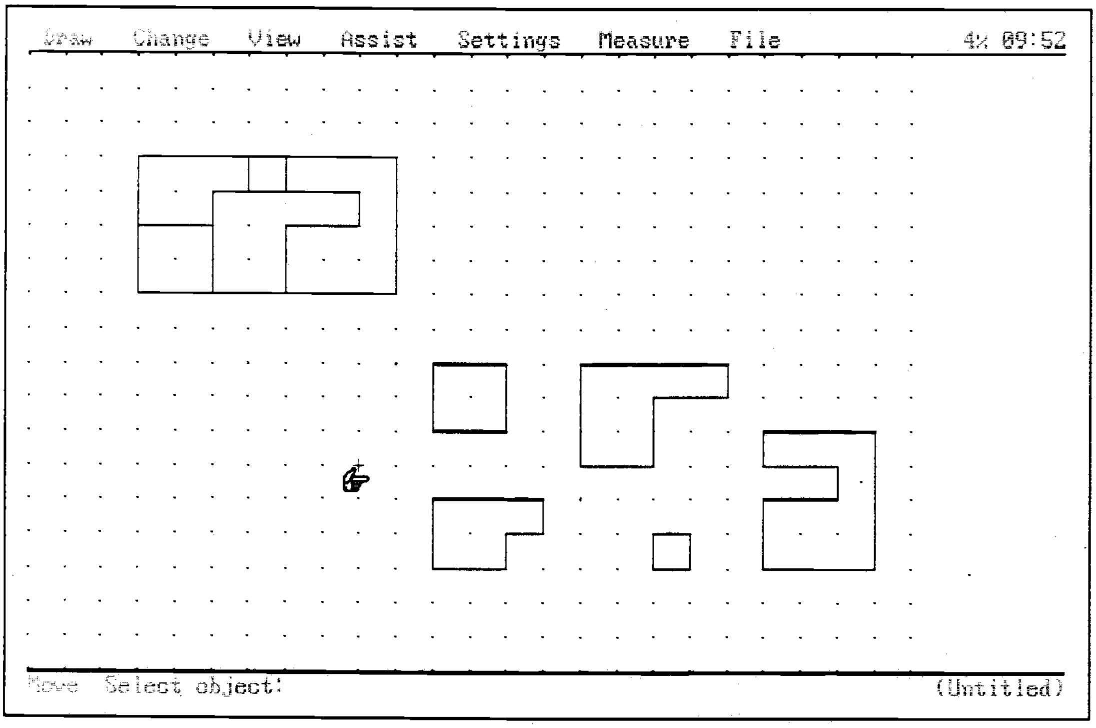
Point at this point to move to and click.

DO THIS



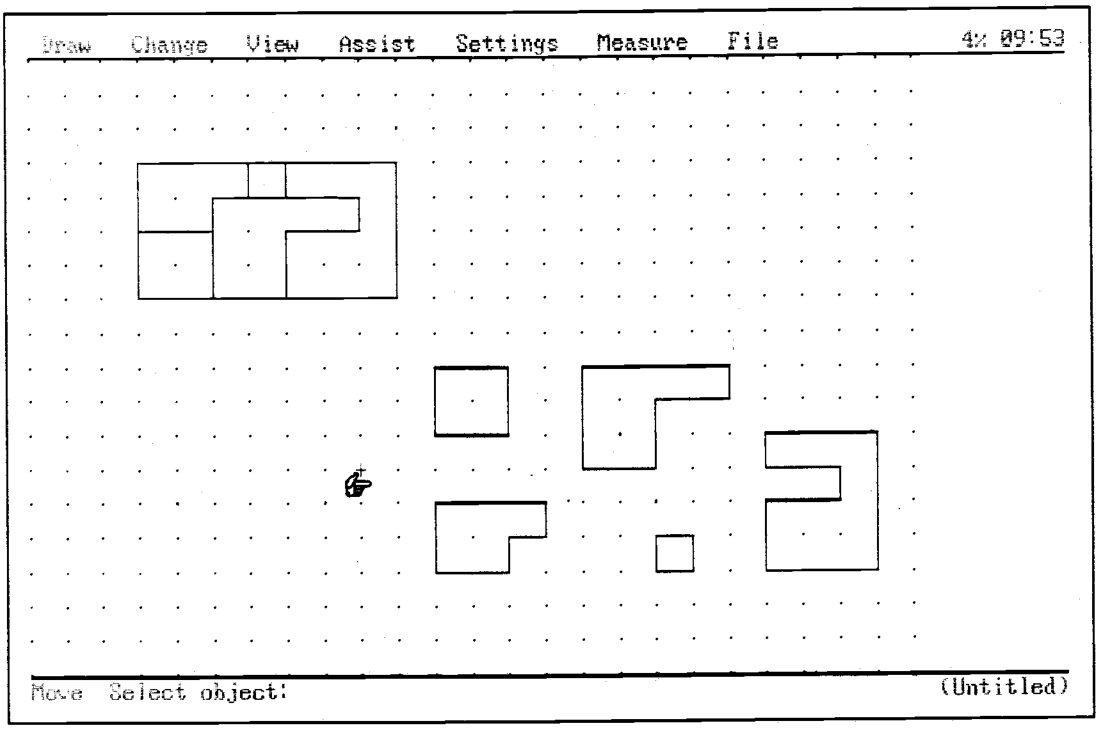
Select [Redraw] to make your dots come back.

DO THIS



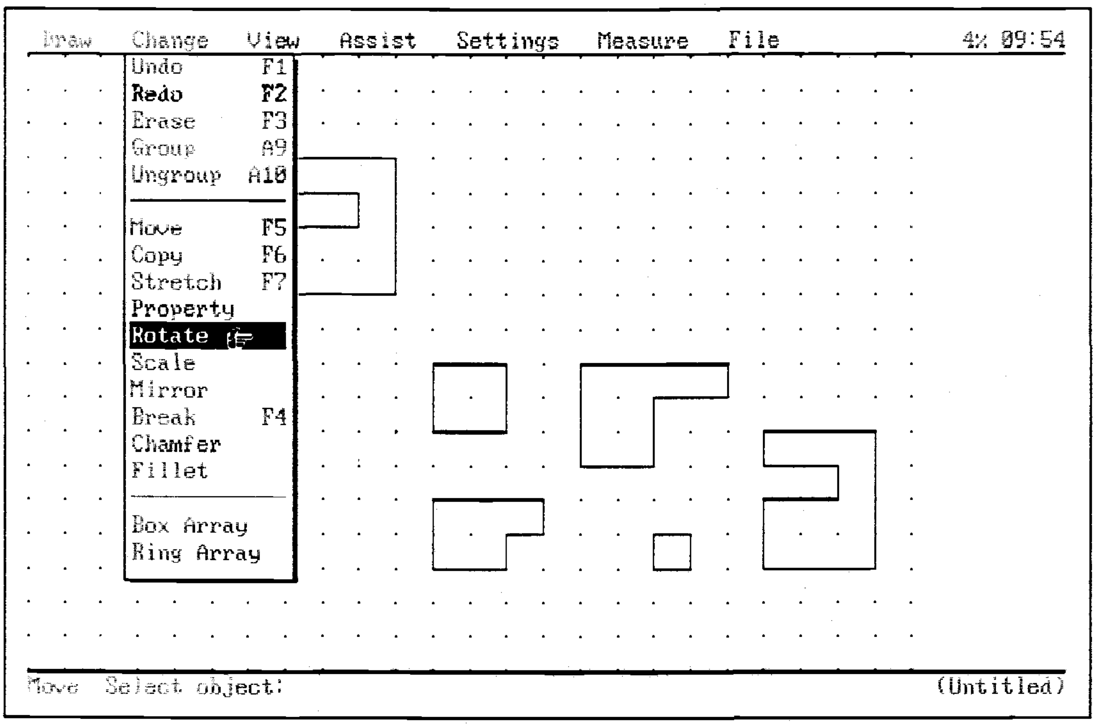
Move your puzzle parts like this. It's OK if they are not exact.

DO THIS



Use the [Move] command and put the puzzle back together.

DO THIS

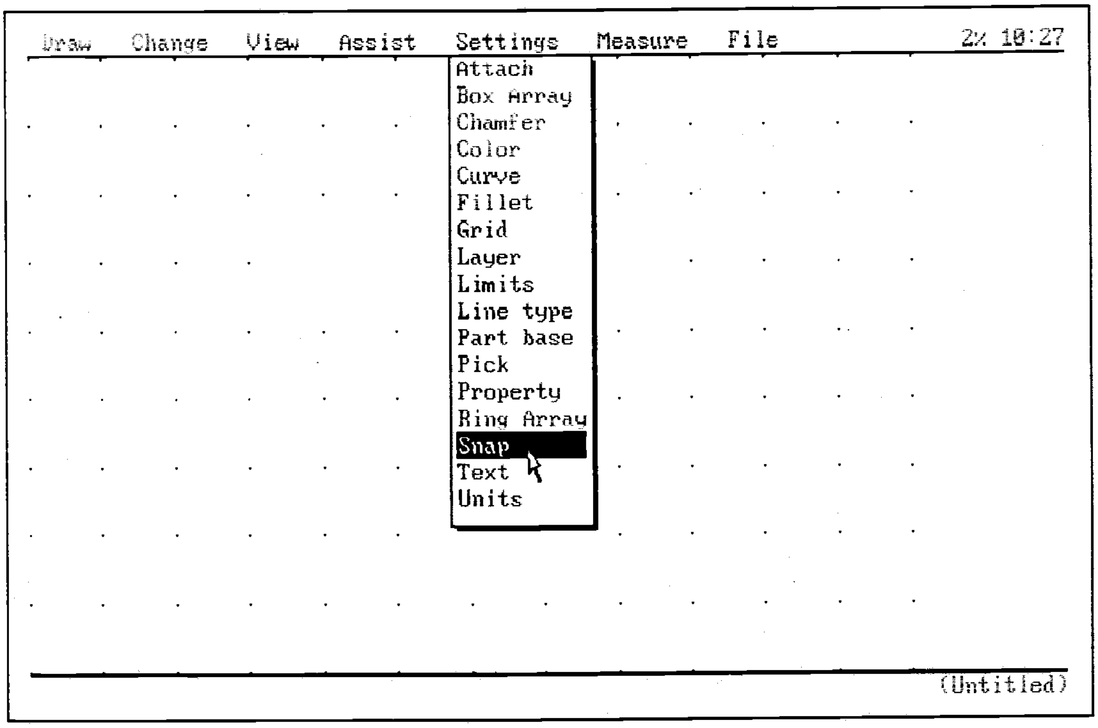


For a challenge, [Rotate] the parts 90 degrees and then build it.

DO THIS

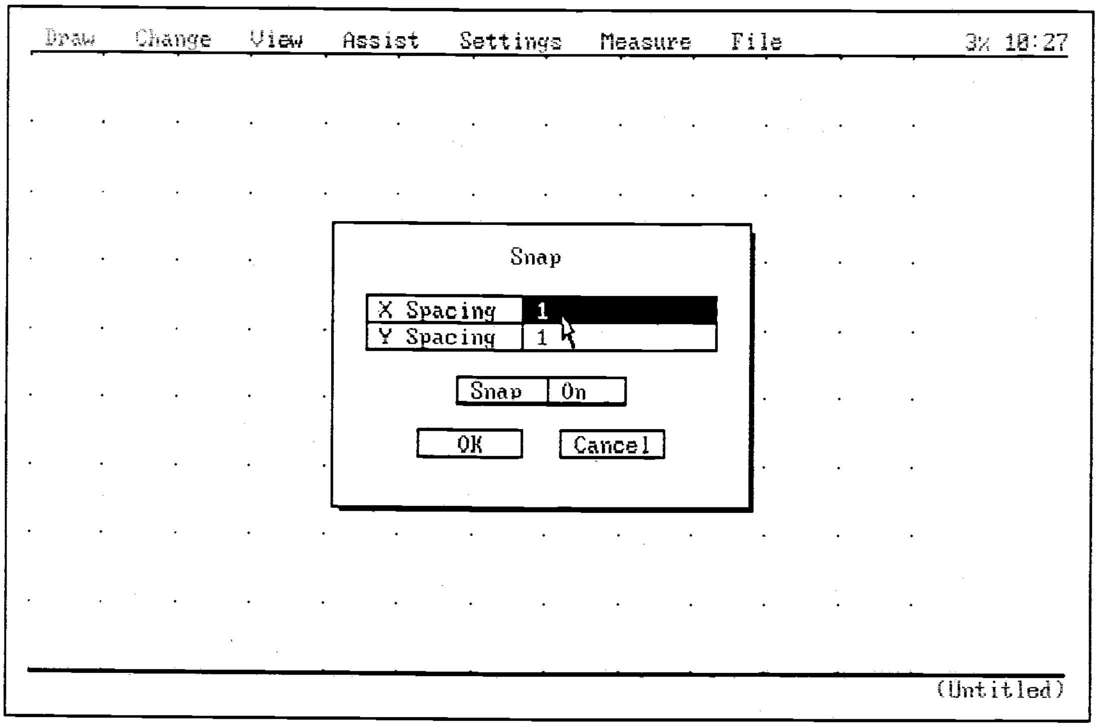
Stop Here

Part 2



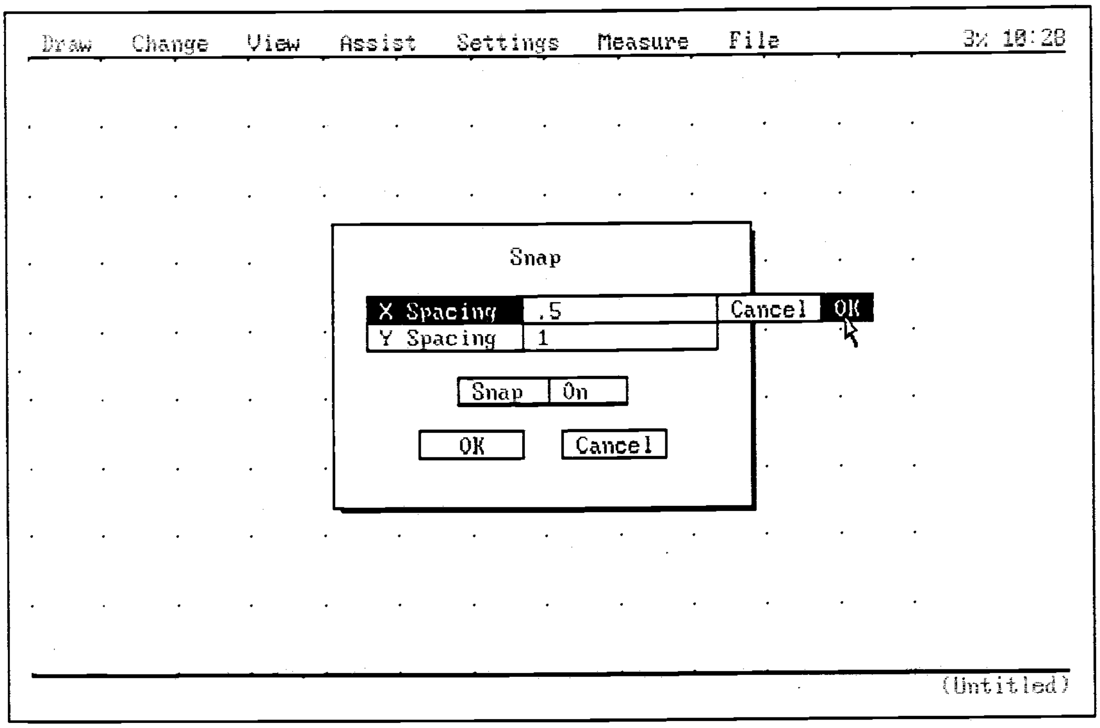
Let's change the snap. Select [Snap].

DO THIS



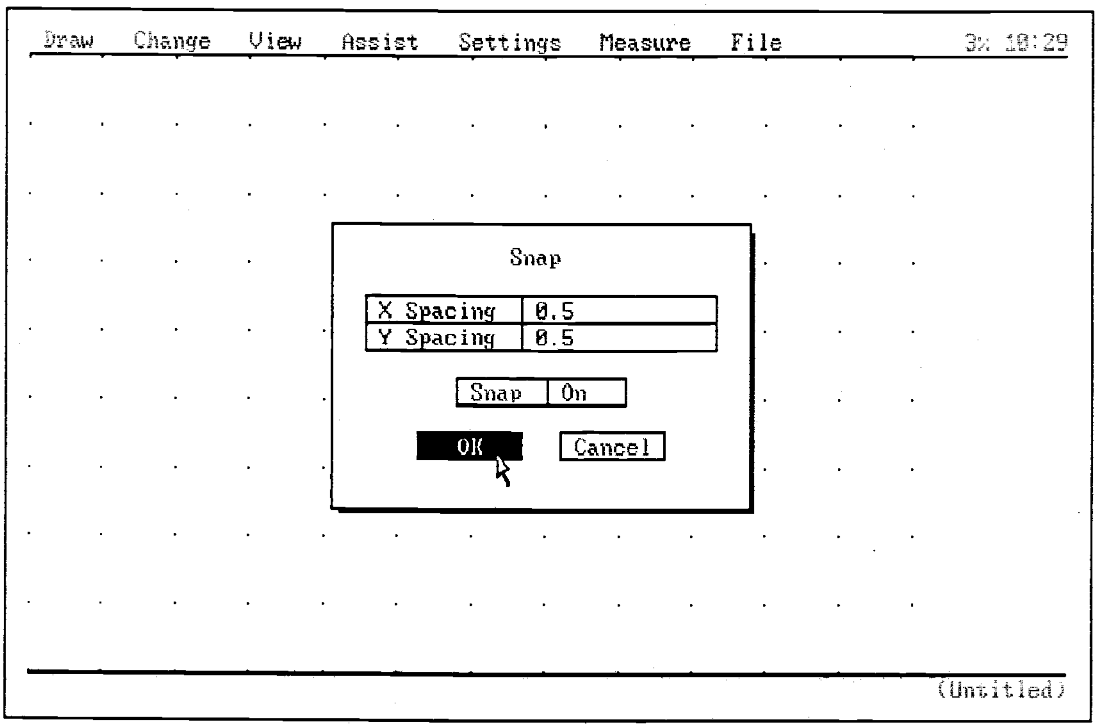
Change X spacing to .5

DO THIS



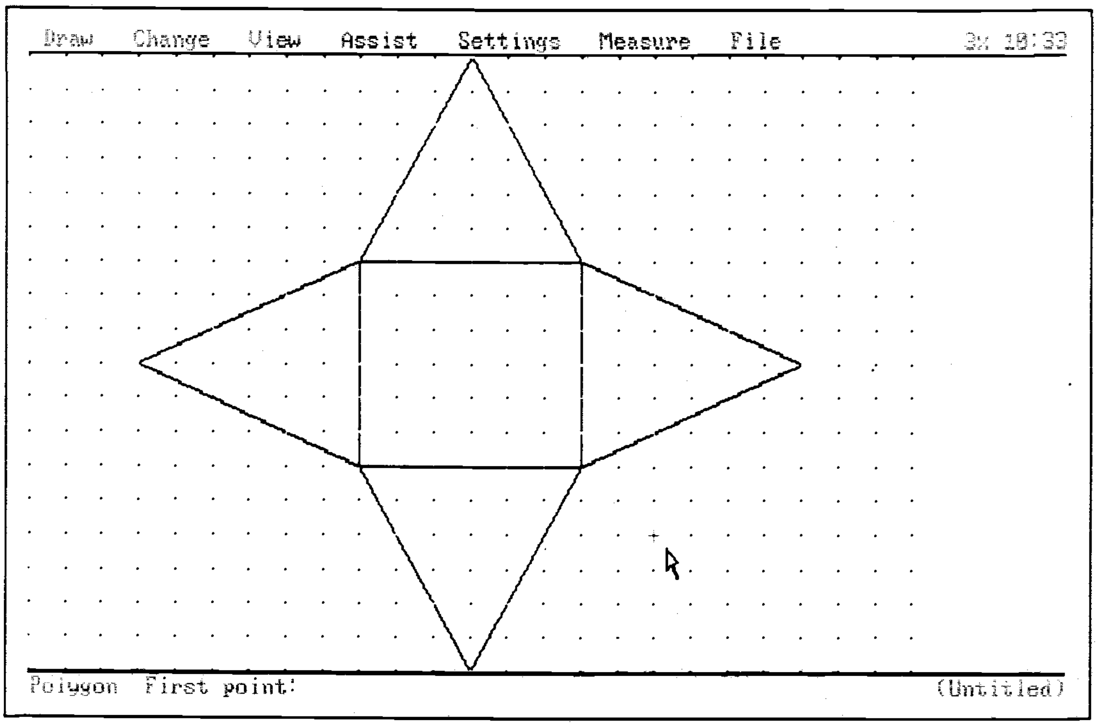
Select [OK].

DO THIS



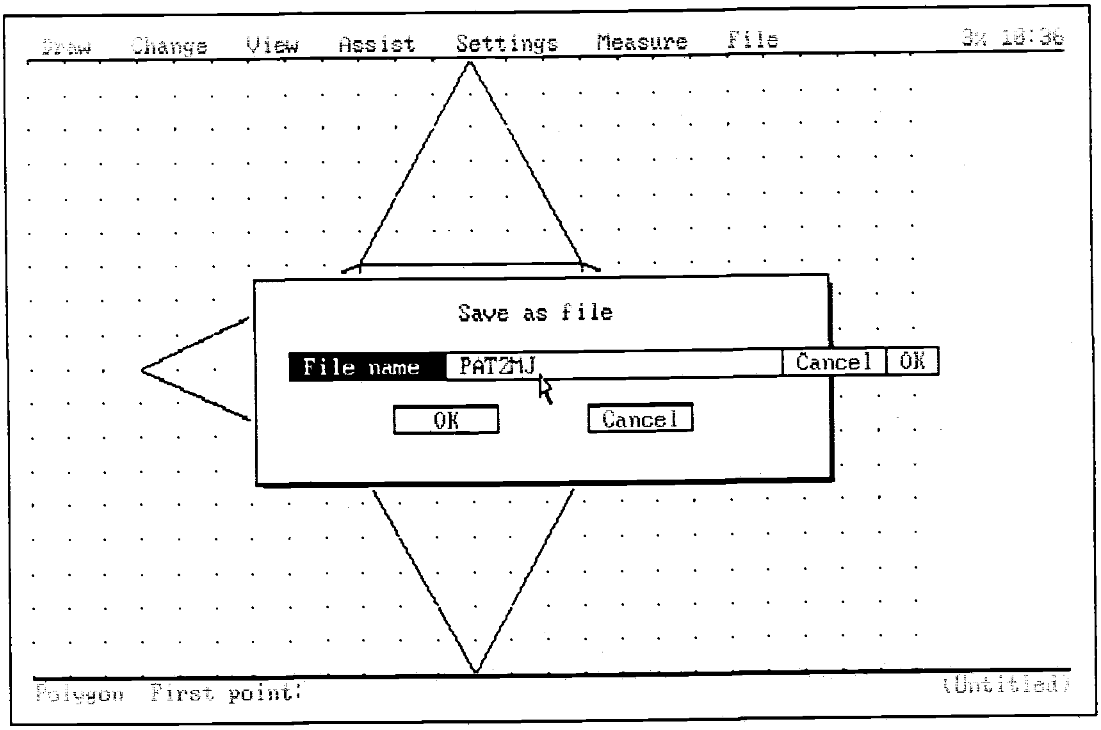
Select [OK] again.

DO THIS



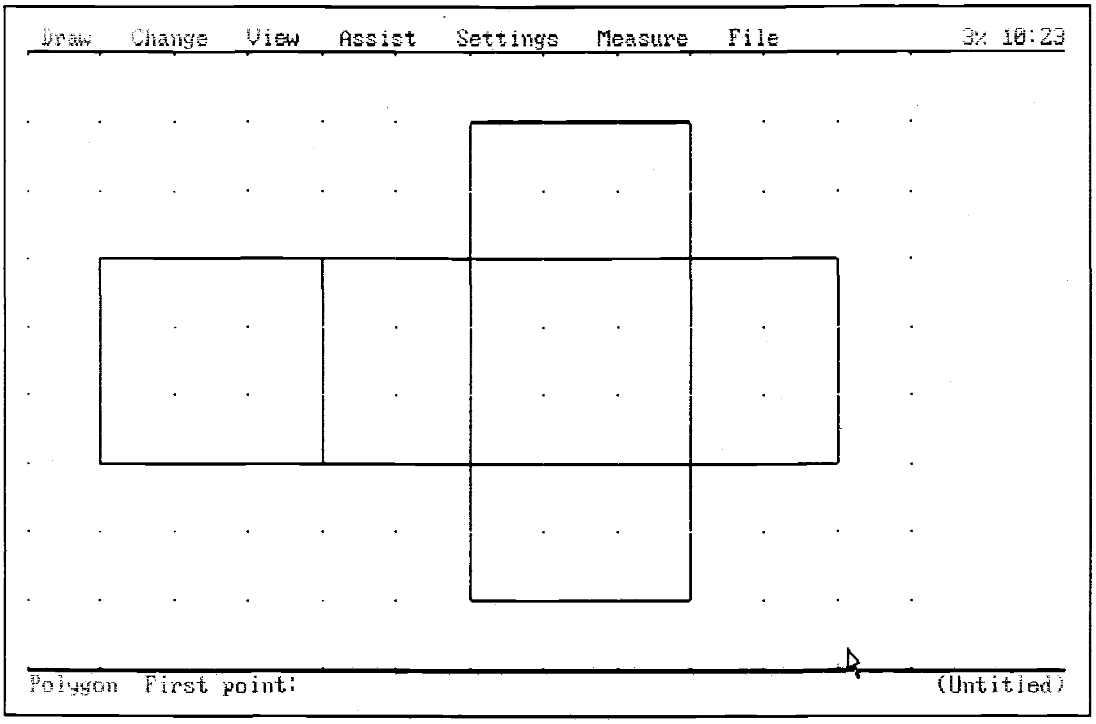
Draw this pattern.

DO THIS



Save these patterns as PAT and your initials, like PAT1MJ and PAT2MJ.

DO THIS



Now, draw this pattern design.

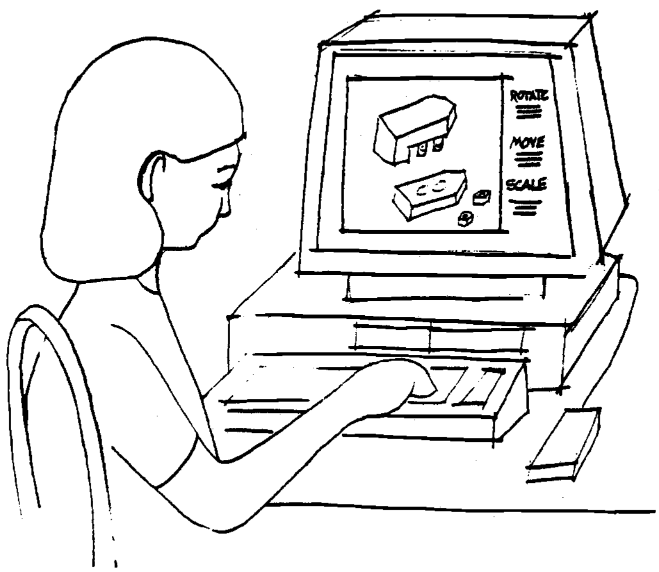
DO THIS

THIS IS THE END OF THE SESSION

The Creative Technologies Project

by Mark L. Merickel

in cooperation with
Autodesk, Inc., the Novato School District,
and Oregon State University



The Workstation Research Project
Instruction Booklet

3

Introduction

The creative technologies project is designed to introduce students to new and exciting ways to use computers. The workstation project introduces students to the processes of developing and manipulating three-dimensional geometric models. It is believed that this development and interaction with three-dimensional models will enhance certain cognitive abilities. Included in these are: visual memory, spatial and visual abilities, displacement and transformation abilities, creativity, and spatially related problem solving abilities.

To complete this project the participants will use a computer workstation operating under DOS. The participants will be using a modified version of the AutoCAD (R) program by Autodesk, Inc.

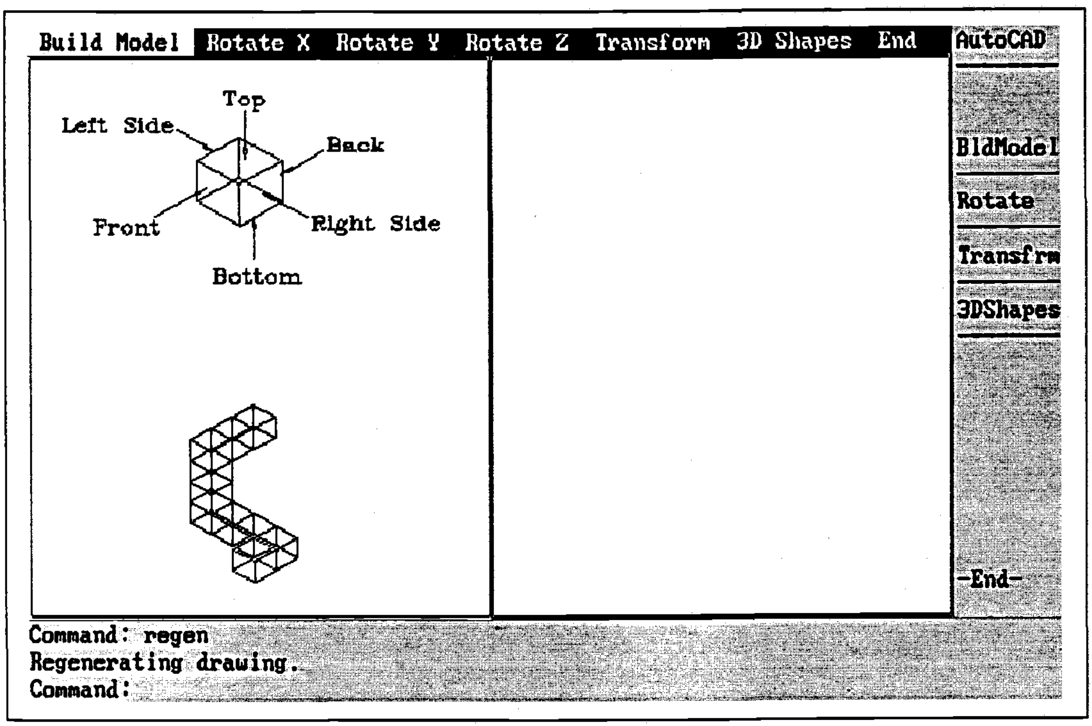
The following pages contain the instructions for the project. Each participant should be seated at a workstation before starting the project. The instructions are designed to be followed, and performed on the workstations, in sequence. If the participant becomes confused at any time throughout the project, it is recommended that the "instructor" assist them with restarting the project from the beginning.

Instructions

The following pages show you how to develop and rotate a "cube model." The cube model that you develop should match the example model. The example model will appear on the left half of the screen when you start the project.

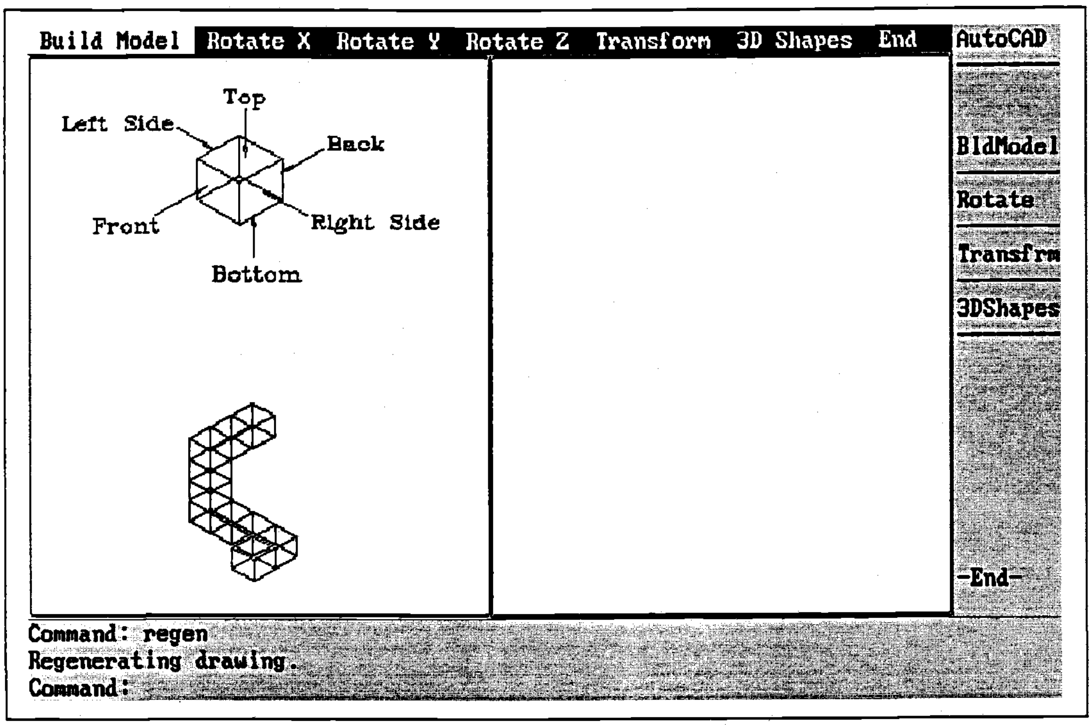
The following pages give written instructions for each step of the project. The instructions will appear at the bottom of each picture (just like the picture below).

The pictures show you how your screen will look during each step. You should look at the picture first, then read the instructions. After reading the instructions you are to do what the picture shows and the instructions say.



Move cursor to highlight "Build Model" and push the left mouse button.

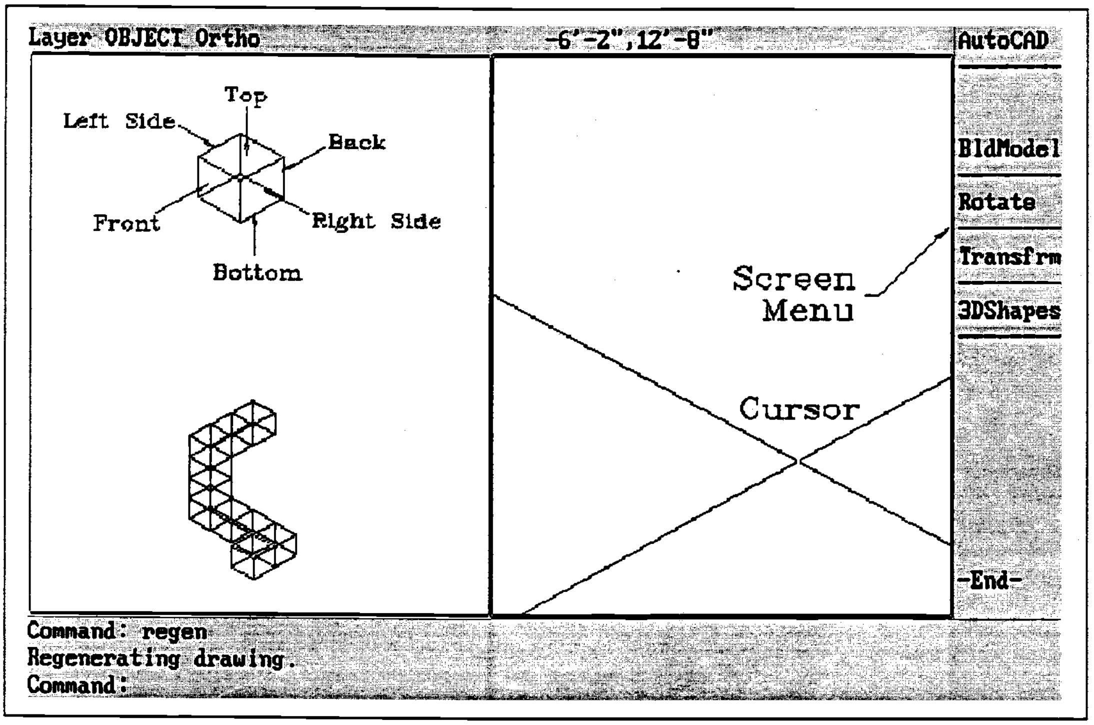
Some of the pictures are examples (just like the one below). These pictures are just to show you the different parts of the computer screen. These picture pages are marked JUST LOOK AND READ. When you are to do something on the computer, the picture pages are marked DO THIS.



This part of the screen is called the pull-down menu bar.

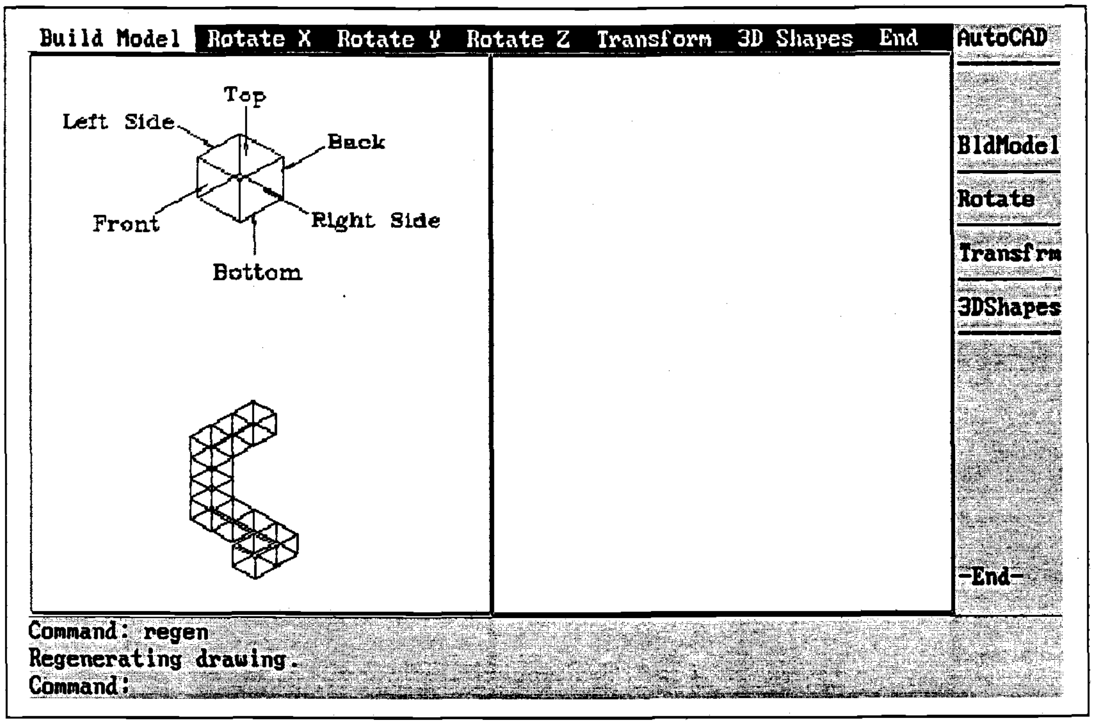
JUST LOOK AND READ

Now turn the page and follow the instructions.



These parts of the screen are called: the screen menu and the cursor.

JUST LOOK AND READ



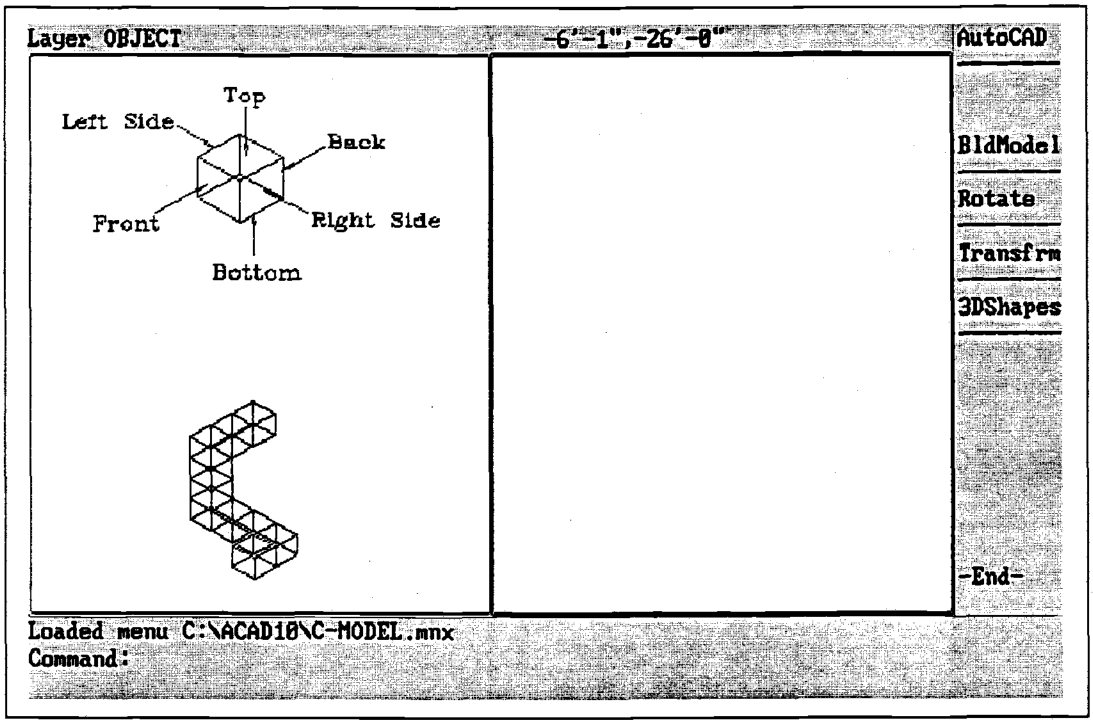
This part of the screen is called the pull-down menu bar.

JUST LOOK AND READ

```
         A U T O C A D
Copyright (C) 1982,83,84,85,86,87,88 Autodesk, Inc.
Release 10 (10/7/88) IBM PC
Advanced Drafting Extensions 3
Serial Number:  79-213129
NOT FOR RESALE

Main Menu

  0.  Exit AutoCAD
  1.  Begin a NEW drawing
  2.  Edit an EXISTING drawing
  3.  Plot a drawing
  4.  Printer Plot a drawing

  5.  Configure AutoCAD
  6.  File Utilities
  7.  Compile shape/font description file
  8.  Convert old drawing file

Enter selection: 2

Enter NAME of drawing: MODEL
```

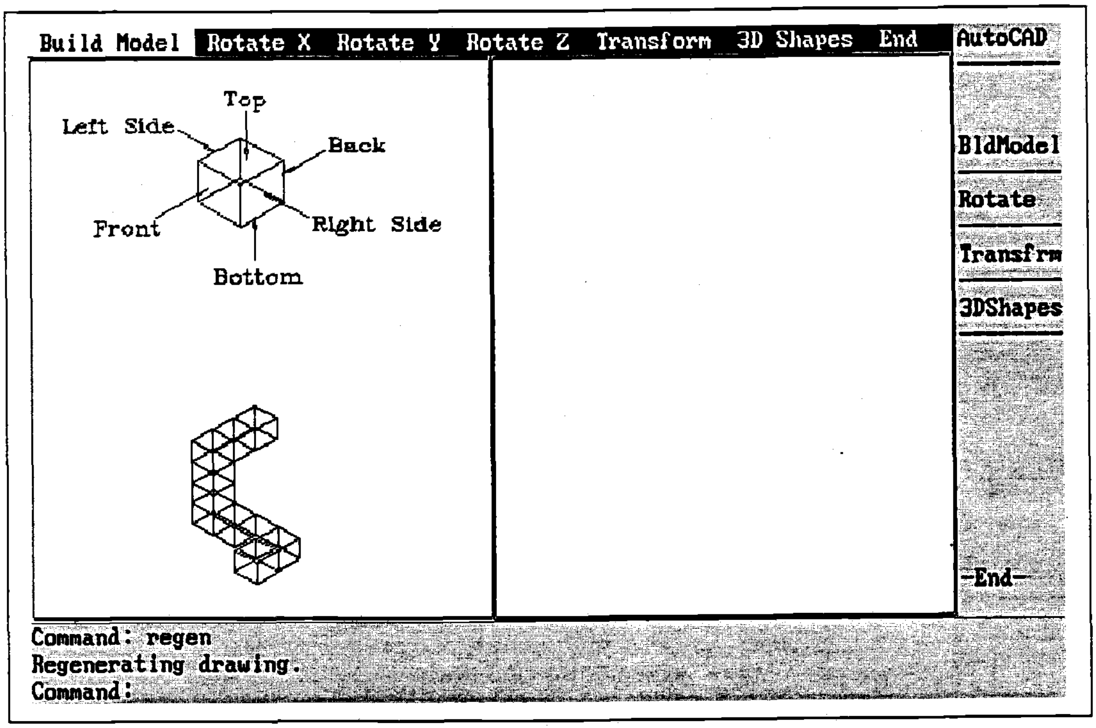
To start, Enter selection: 2   Then Enter NAME of drawing:MODEL

DO THIS



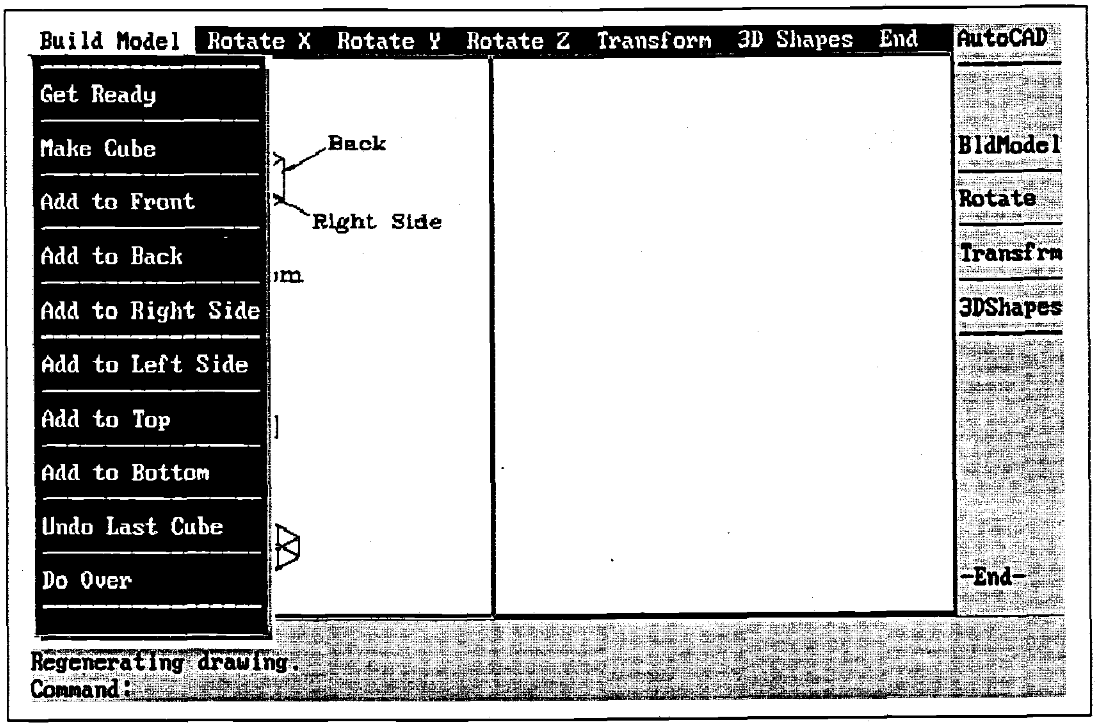
The screen will now look like this.

JUST LOOK AND READ



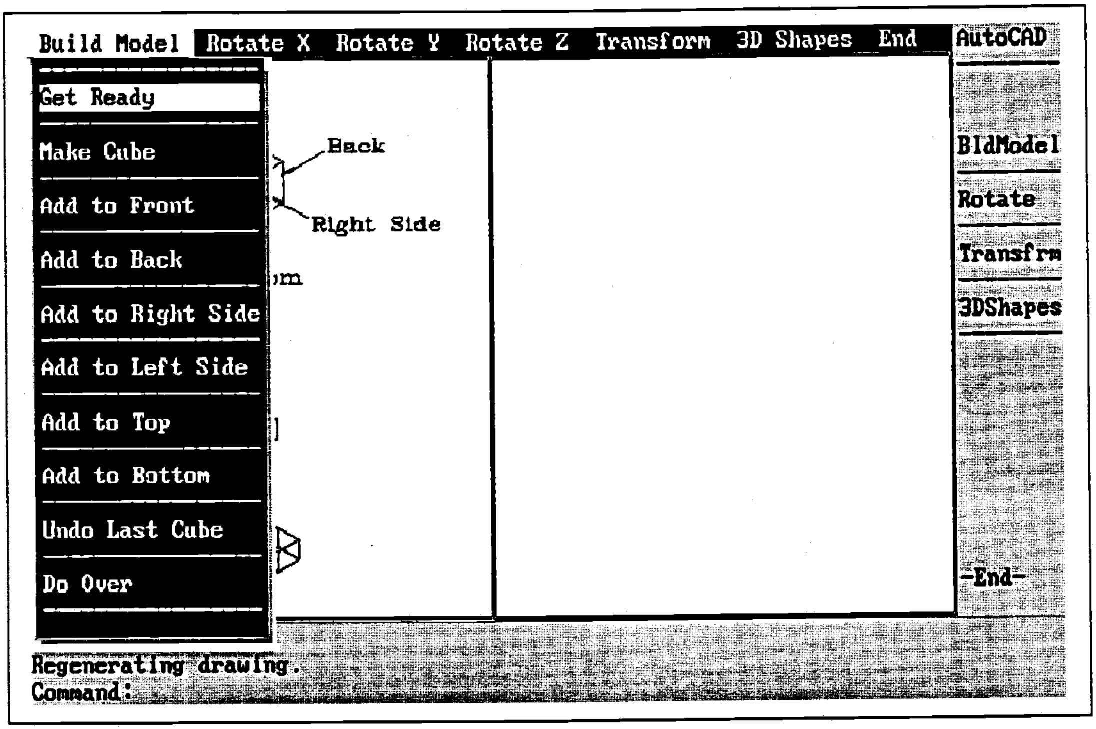
Move cursor to highlight "Build Model" and push the left mouse button.

DO THIS



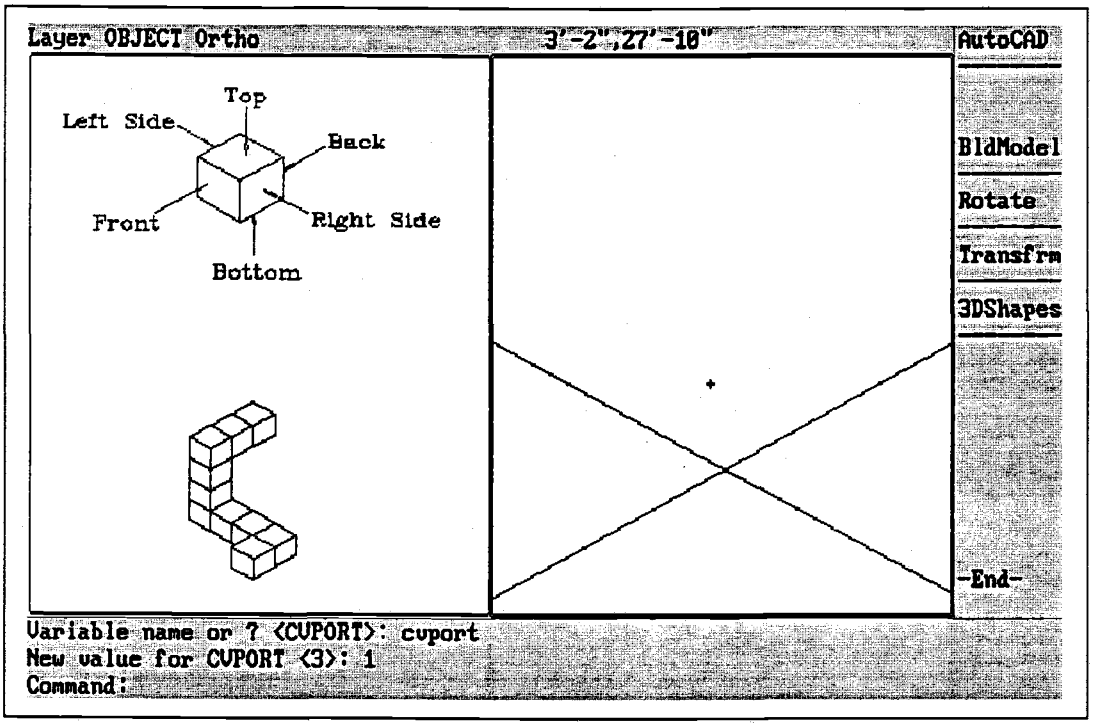
This is a pull-down menu. Each of the menu bar selections have one.

JUST LOOK AND READ



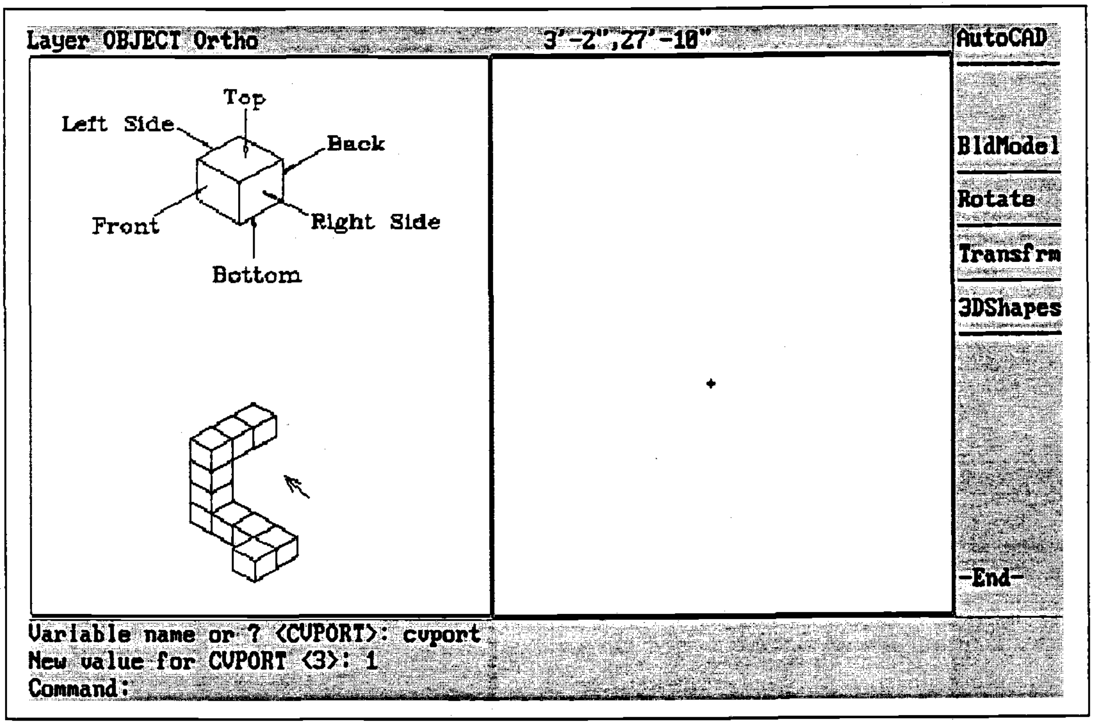
Move mouse to highlight "Get Ready" and push the left mouse button.

DO THIS



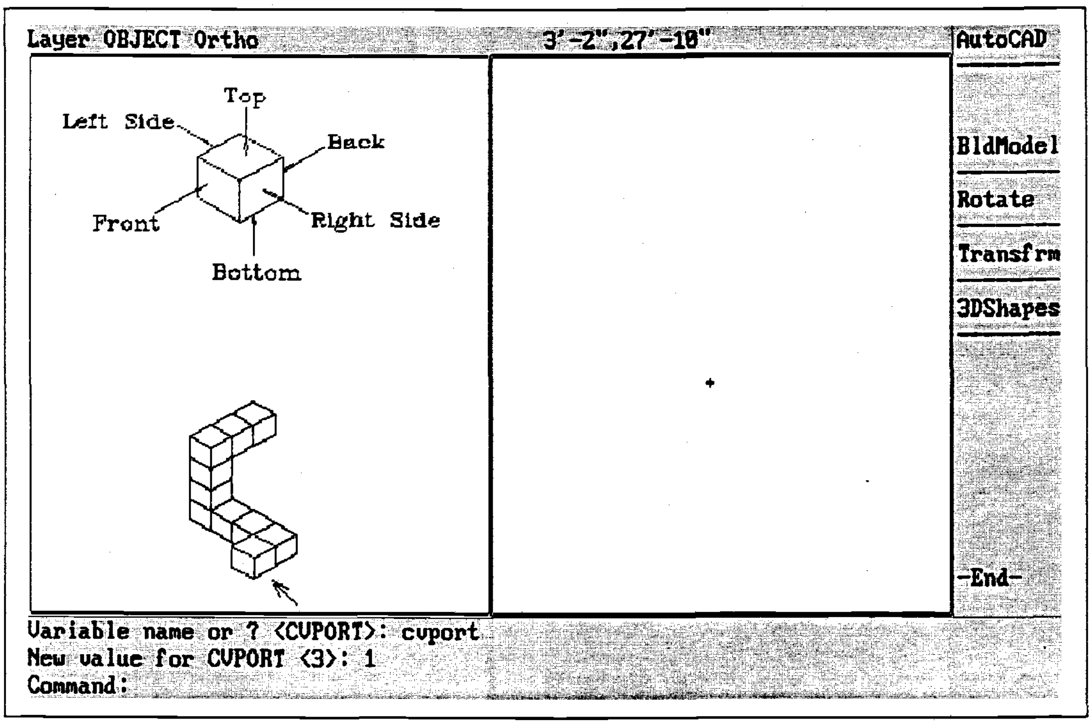
The screen is now ready to draw. It will look like this.

JUST LOOK AND READ



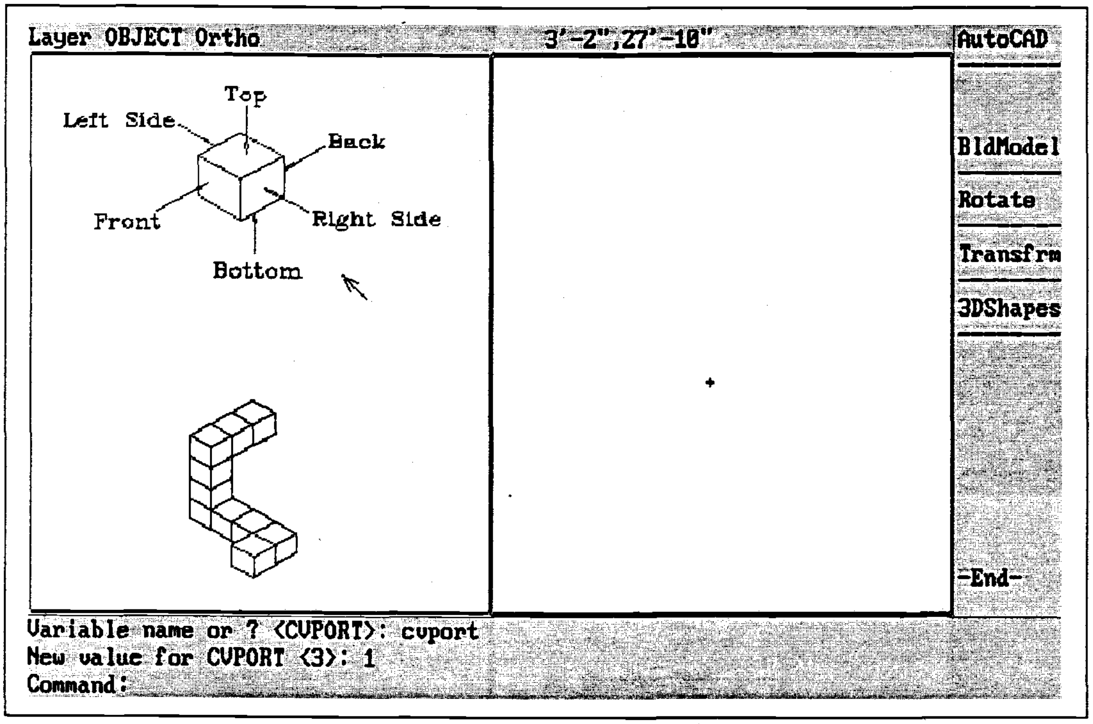
Study the example model that the arrow is pointing at.

JUST LOOK AND READ



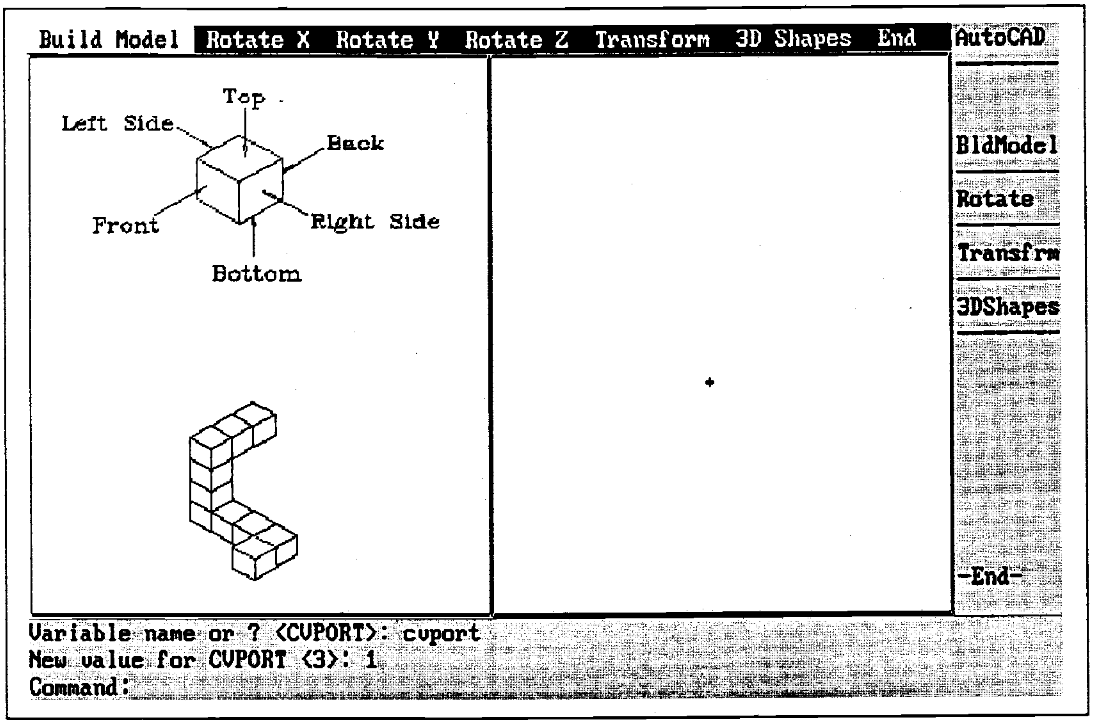
The bottom cube is drawn in red.

JUST LOOK AND READ



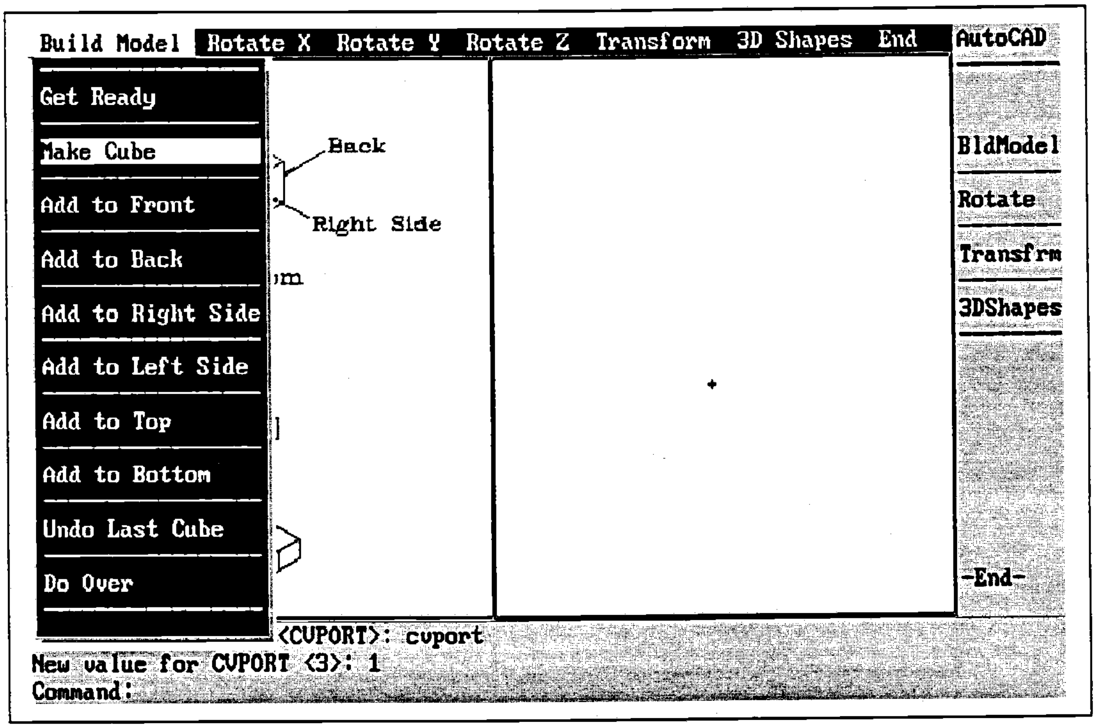
The large red cube shows you the names of each of the cubes sides.

JUST LOOK AND READ



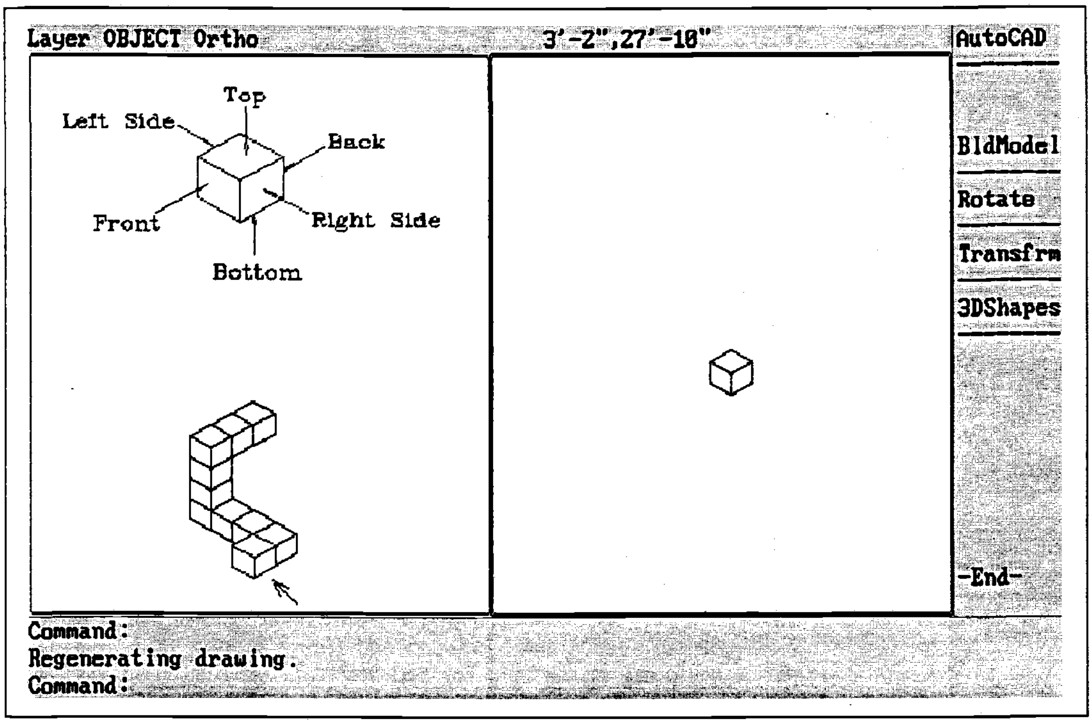
Highlight the selection "Build Model" and push the left mouse button.

DO THIS



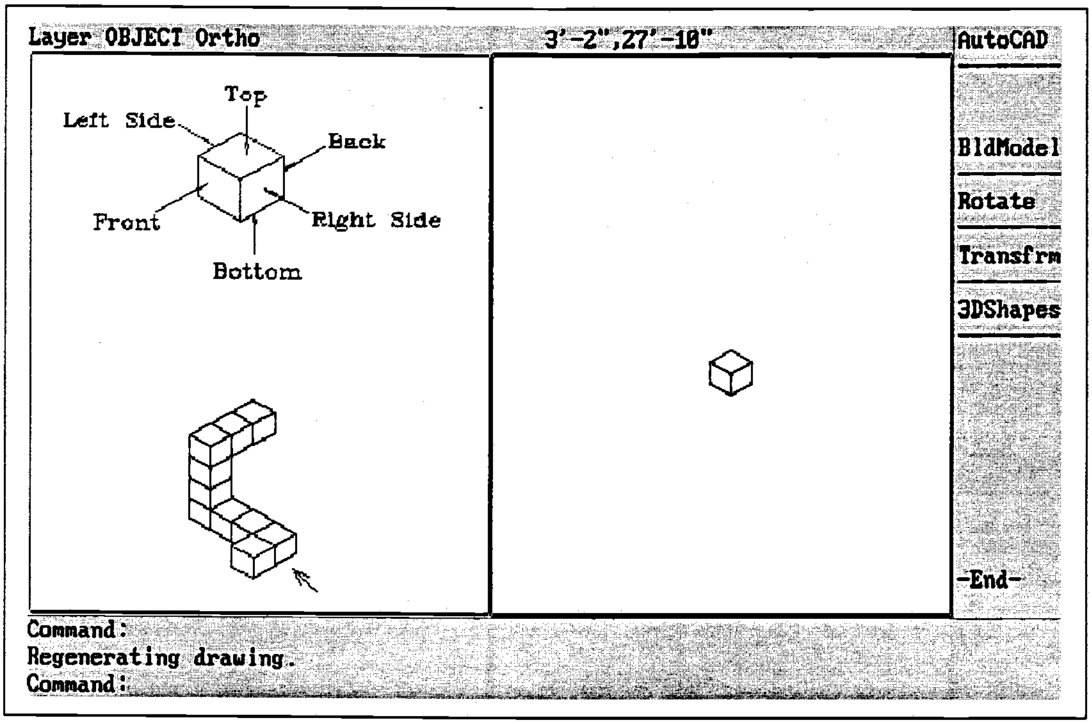
Highlight the selection "Make Cube" and push the left mouse button.

DO THIS



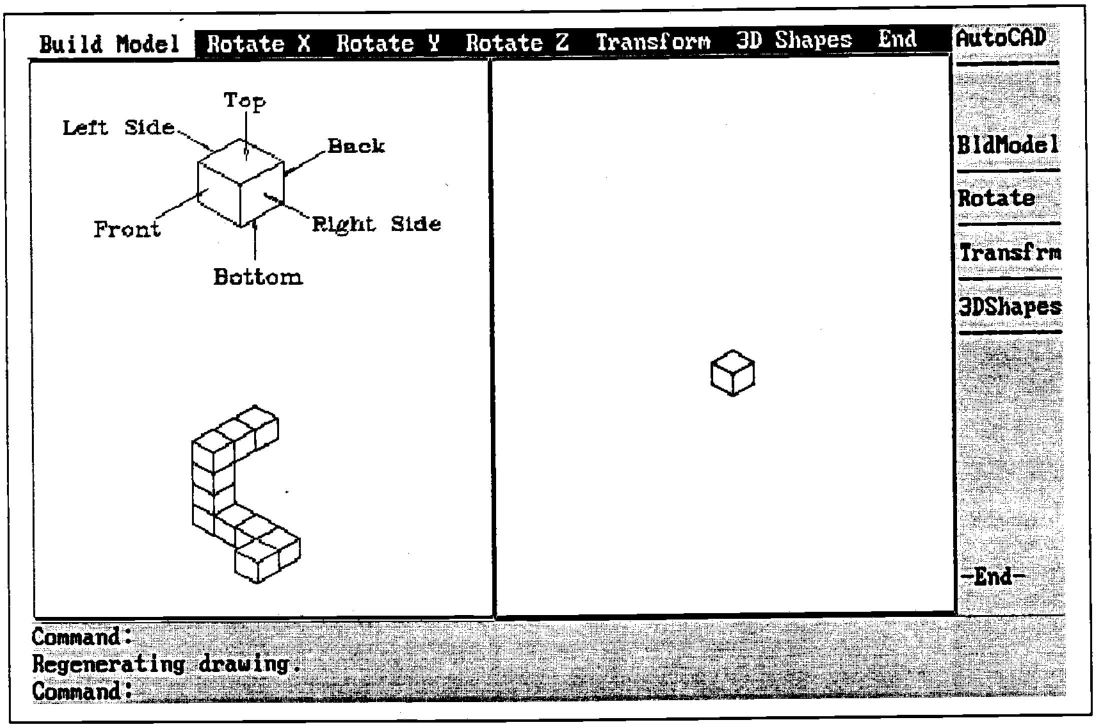
You just created the yellow cube to match the red one in the example.

JUST LOOK AND READ



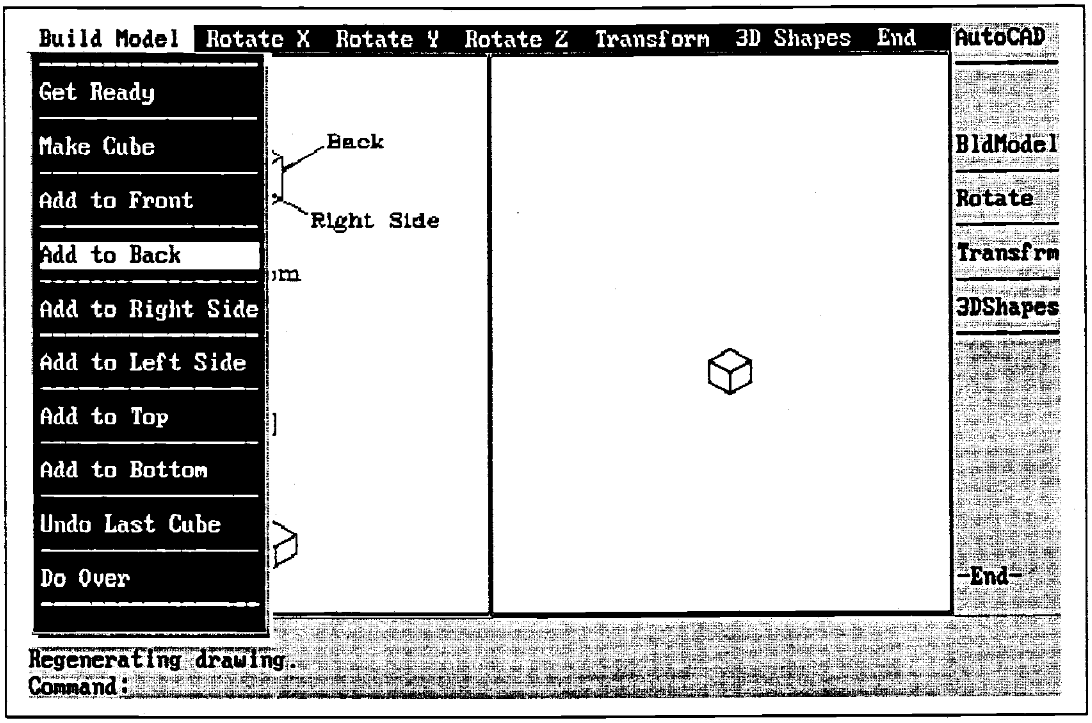
To copy the example, add next cube to the "Back" of the first cube.

JUST LOOK AND READ



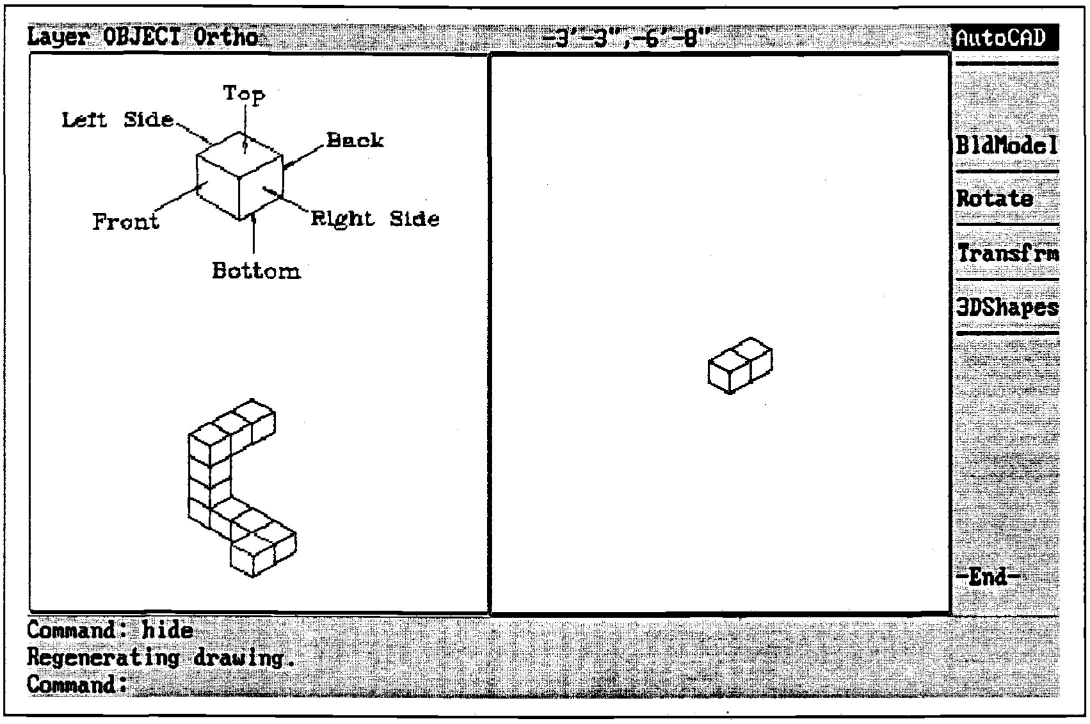
Select "Build Model" again.

DO THIS



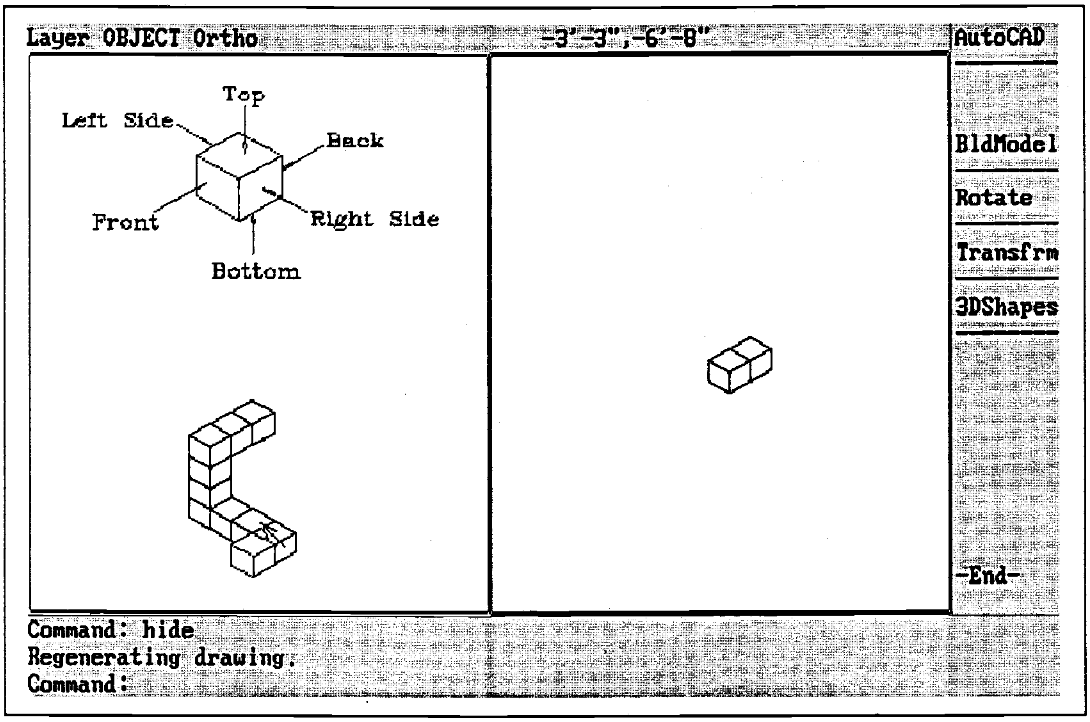
Select "Add to Back".

DO THIS



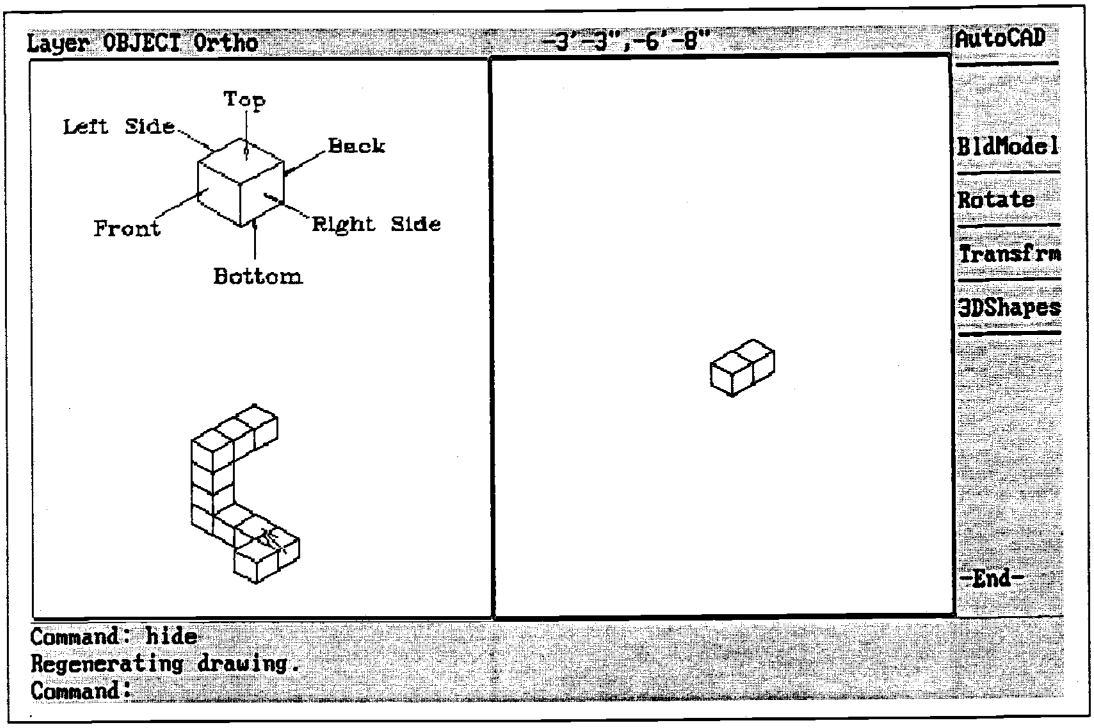
The new cube is added to the back. Like this.

JUST LOOK AND READ



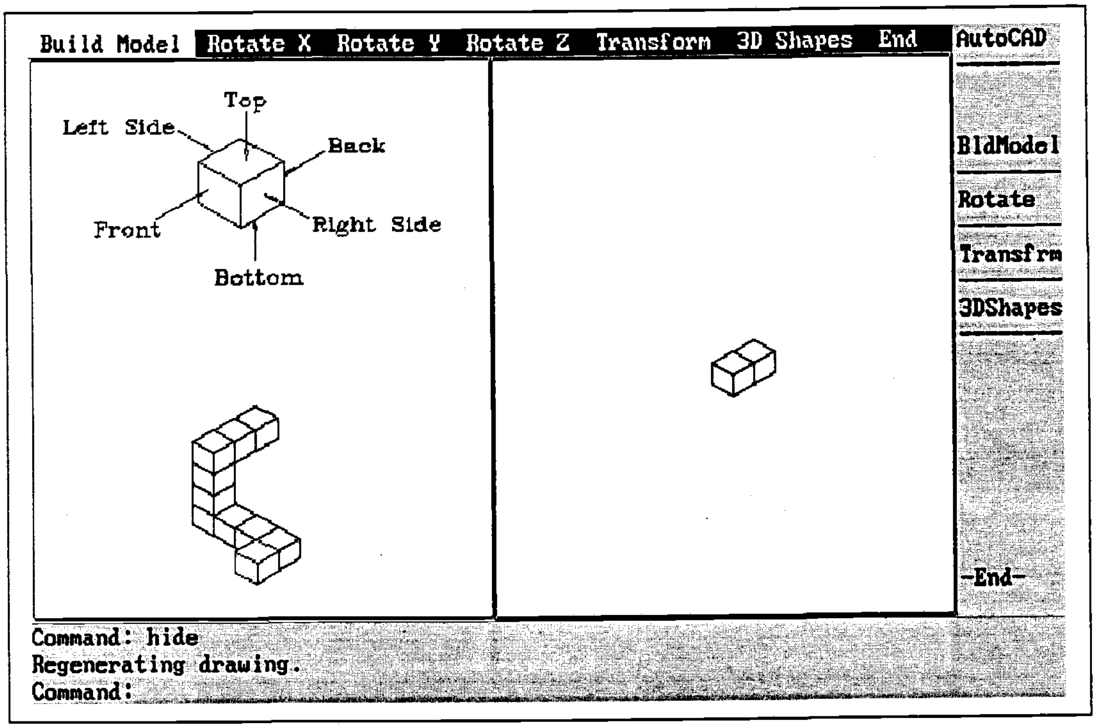
Which side do you need to add the next cube to?

JUST LOOK AND READ



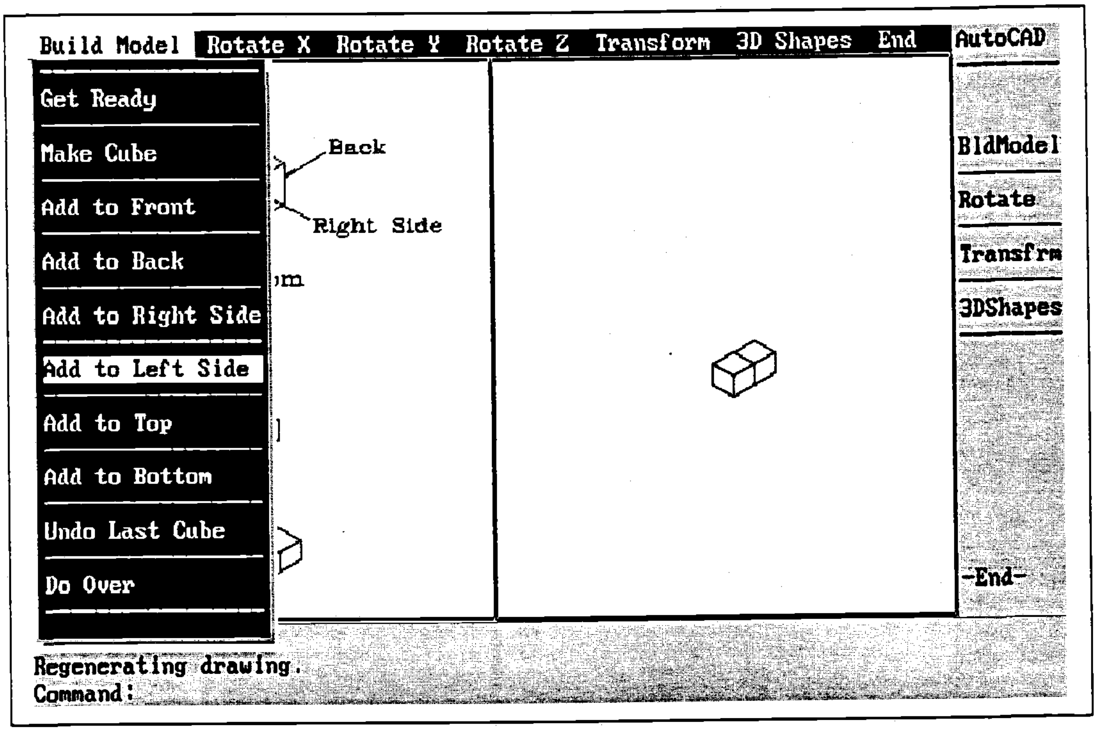
If you think it is to the left, that is correct.

JUST LOOK AND READ



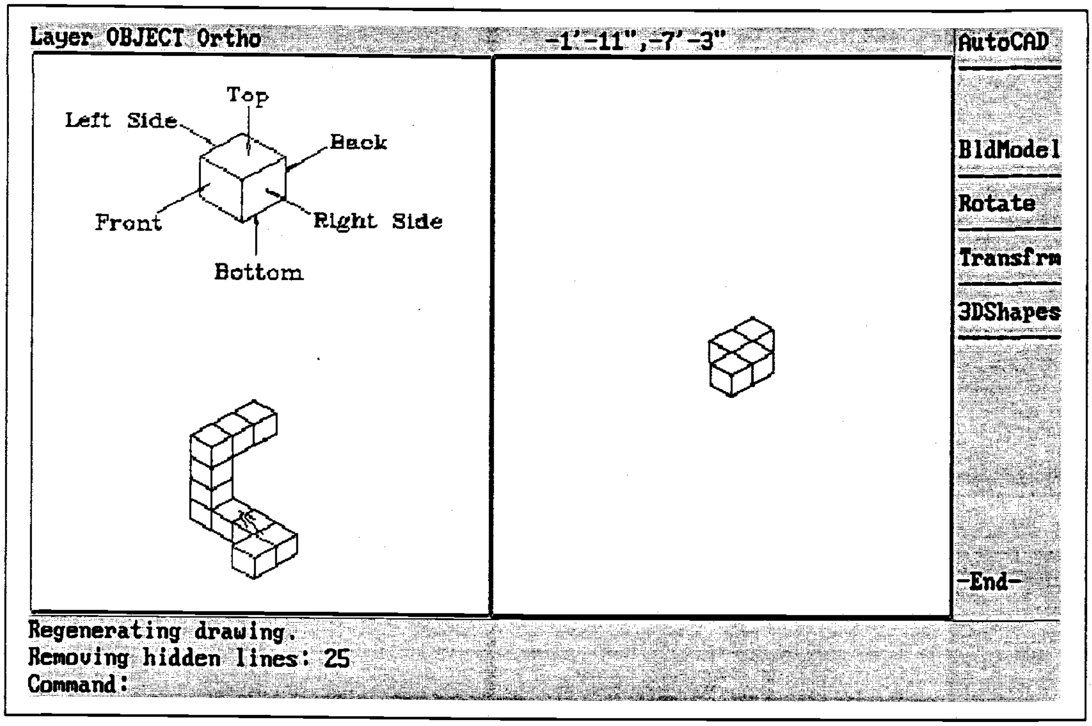
Select "Build Model".

DO THIS



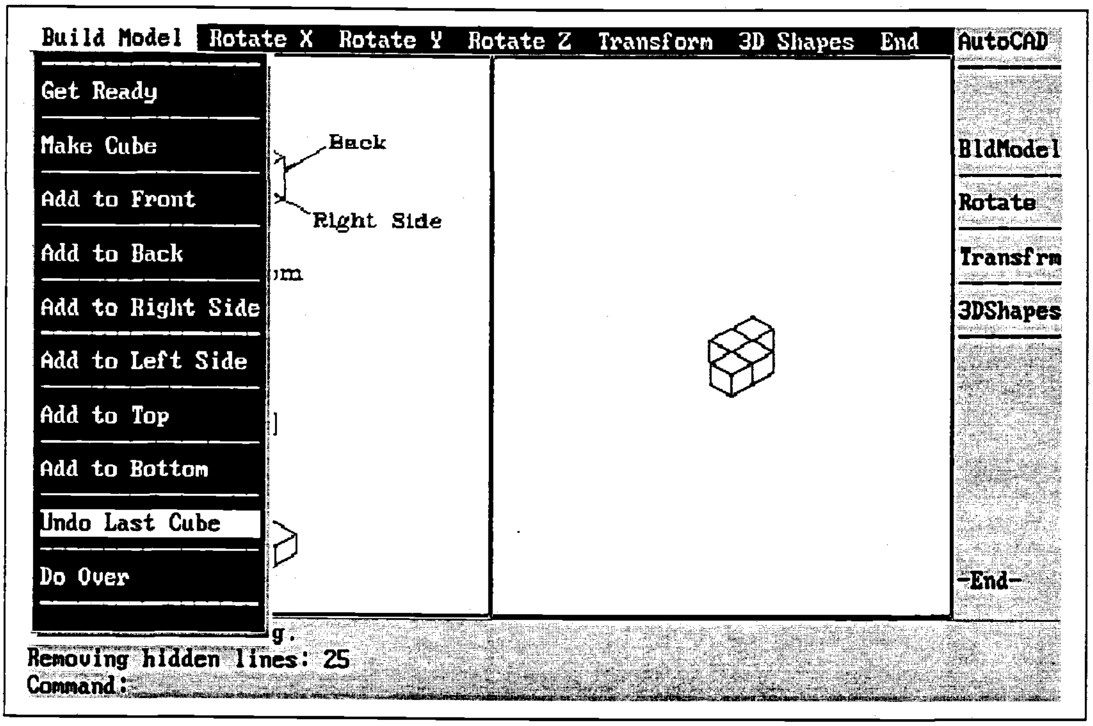
Select "Add to Left Side".

DO THIS



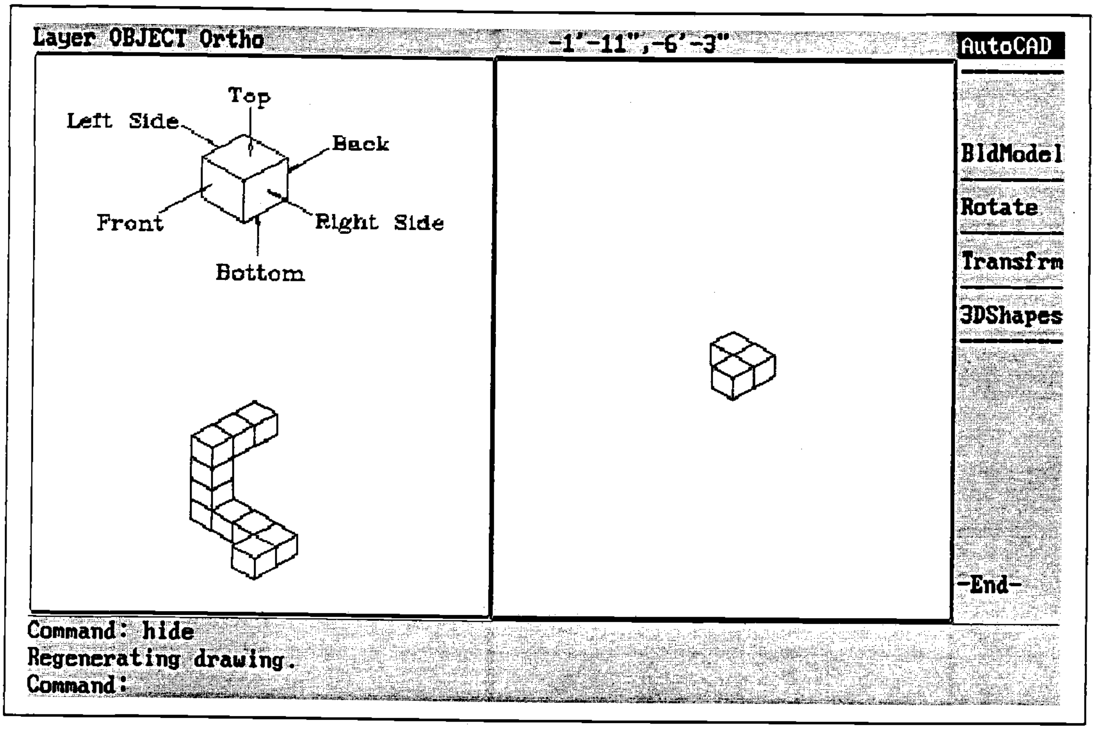
If you make a mistake, it's easy to correct.

JUST LOOK AND READ



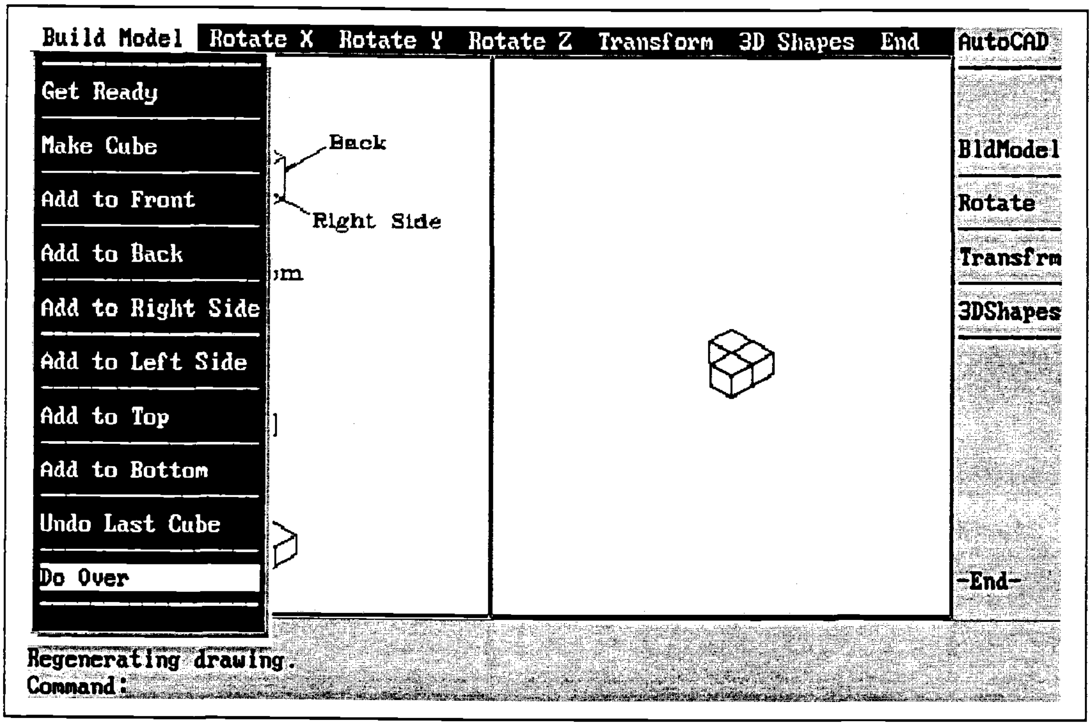
Just select "Undo Last Cube".

JUST LOOK AND READ



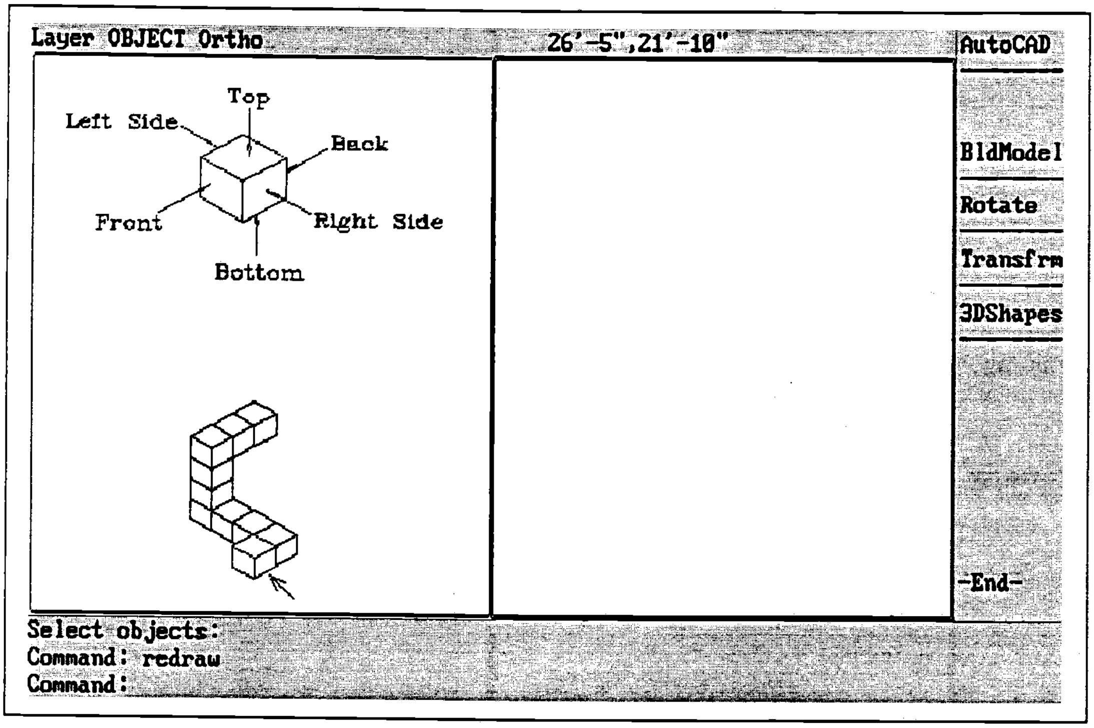
And your last cube is erased. Now try again.

JUST LOOK AND READ



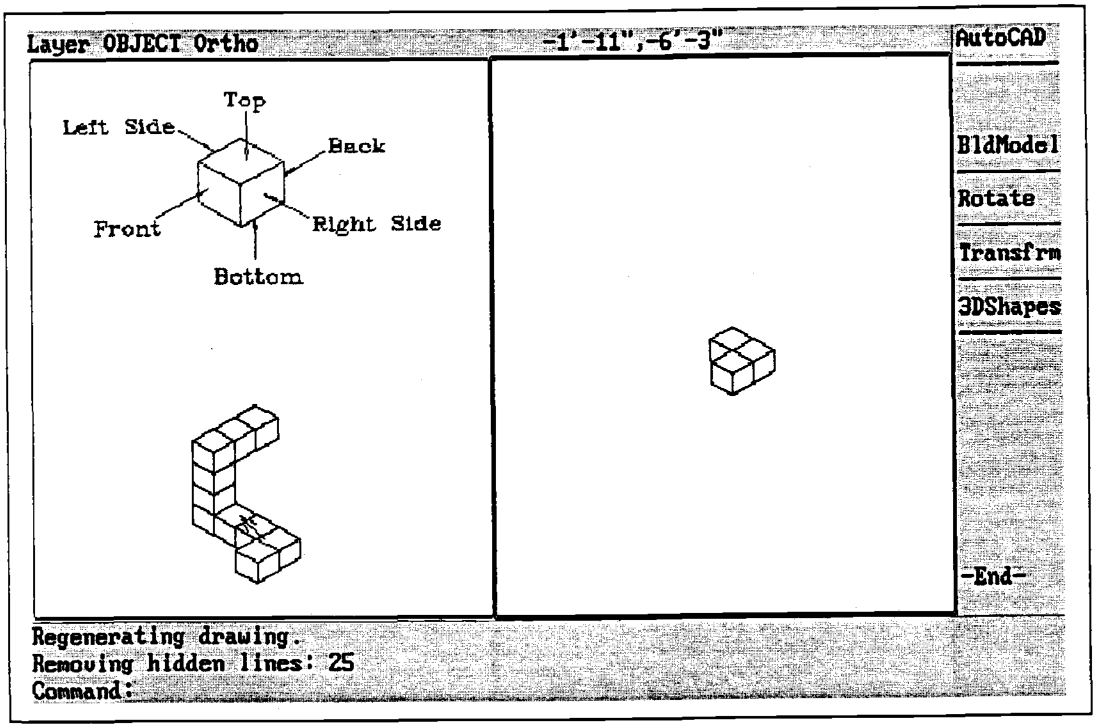
If you would like to start over. Select "Do Over".

JUST LOOK AND READ



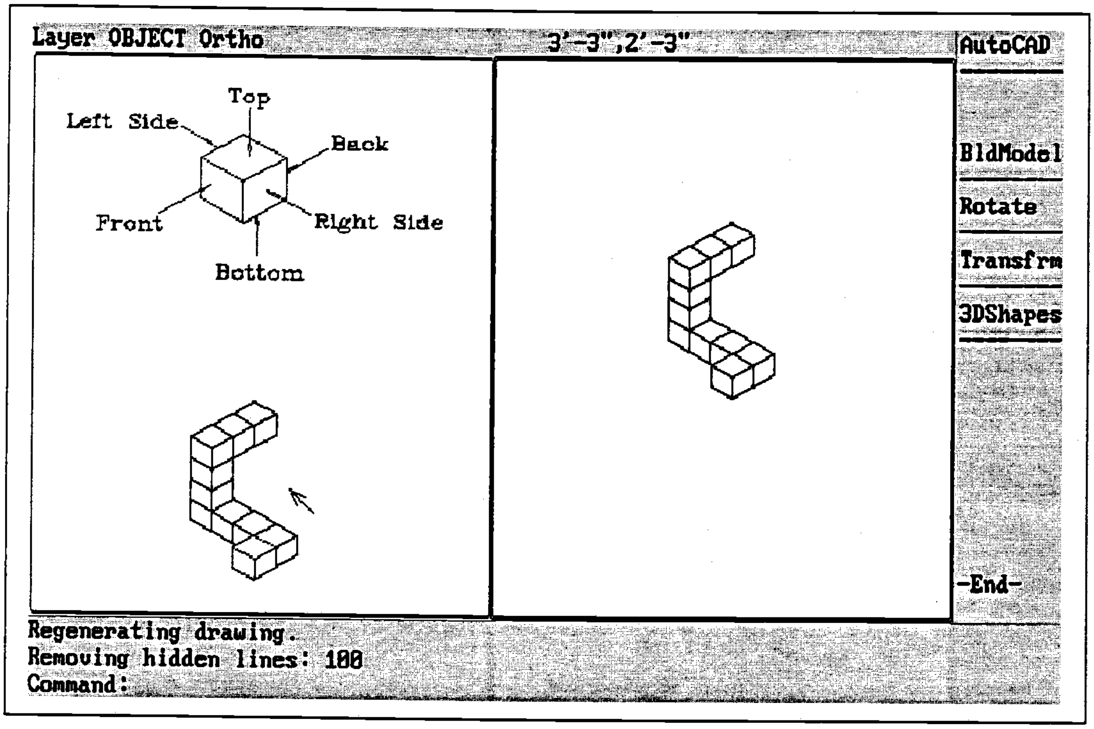
You can now start over from the beginning.

JUST LOOK AND READ



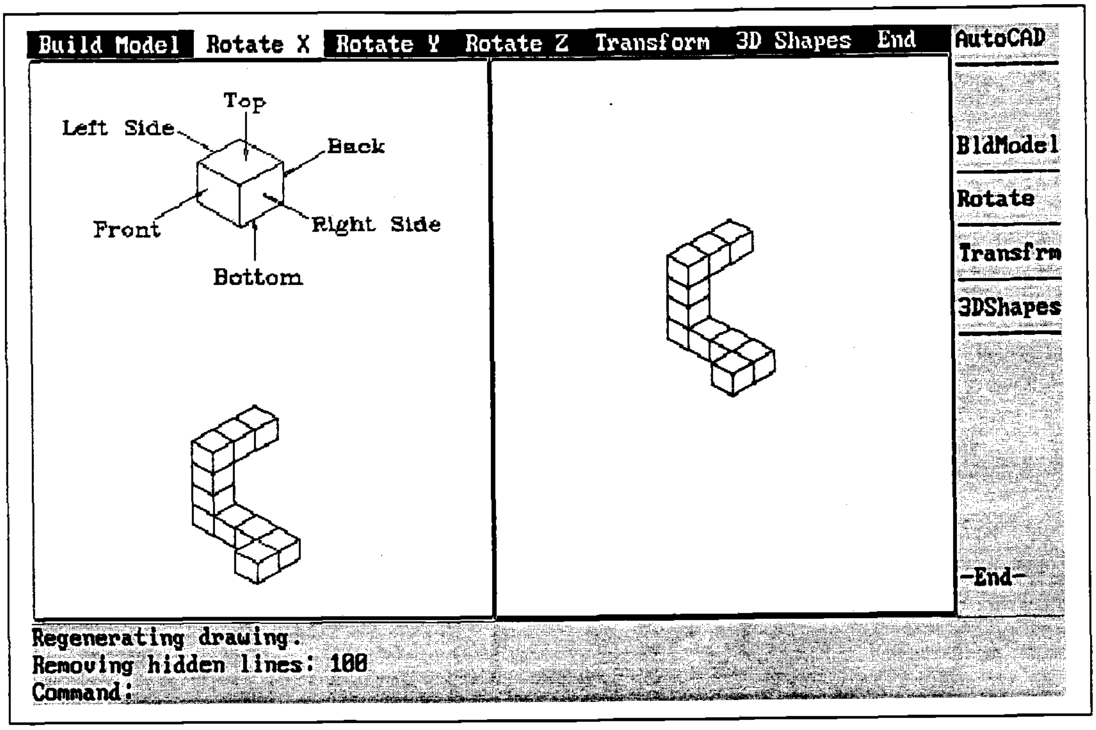
Now, continue to add cubes until the model matches the example.

DO THIS



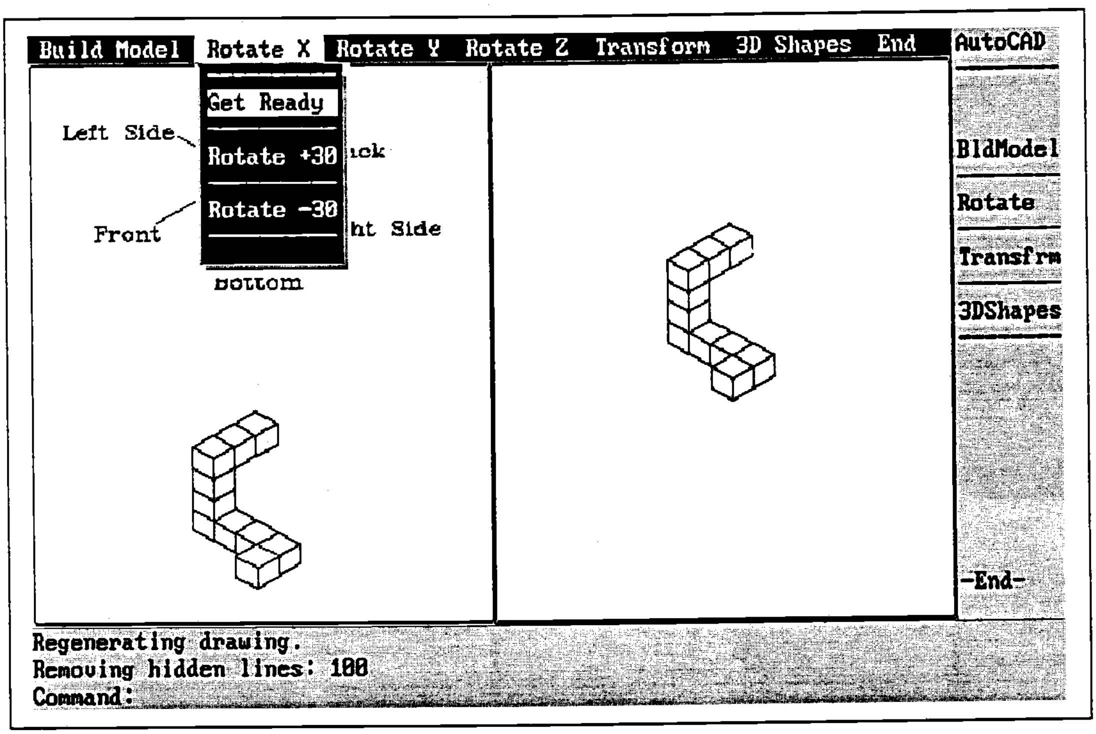
Your finished model should match the example. Like this.

JUST LOOK AND READ



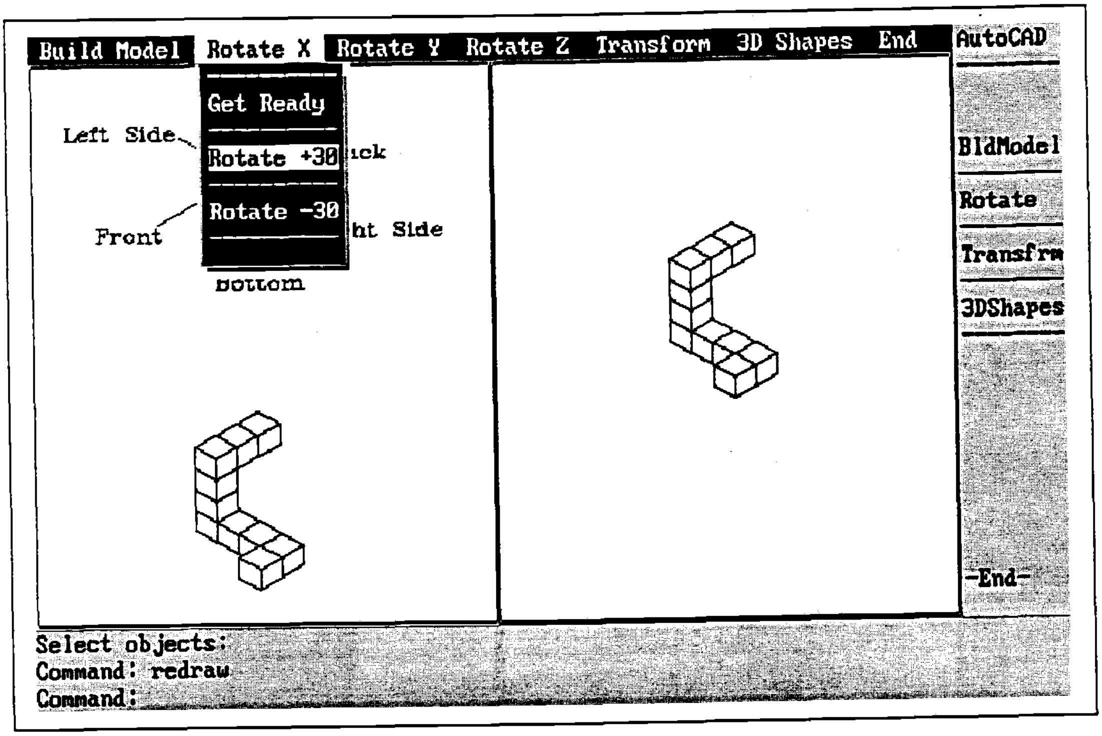
Now, let's rotate the model along the X axes. Select "Rotate X".

DO THIS



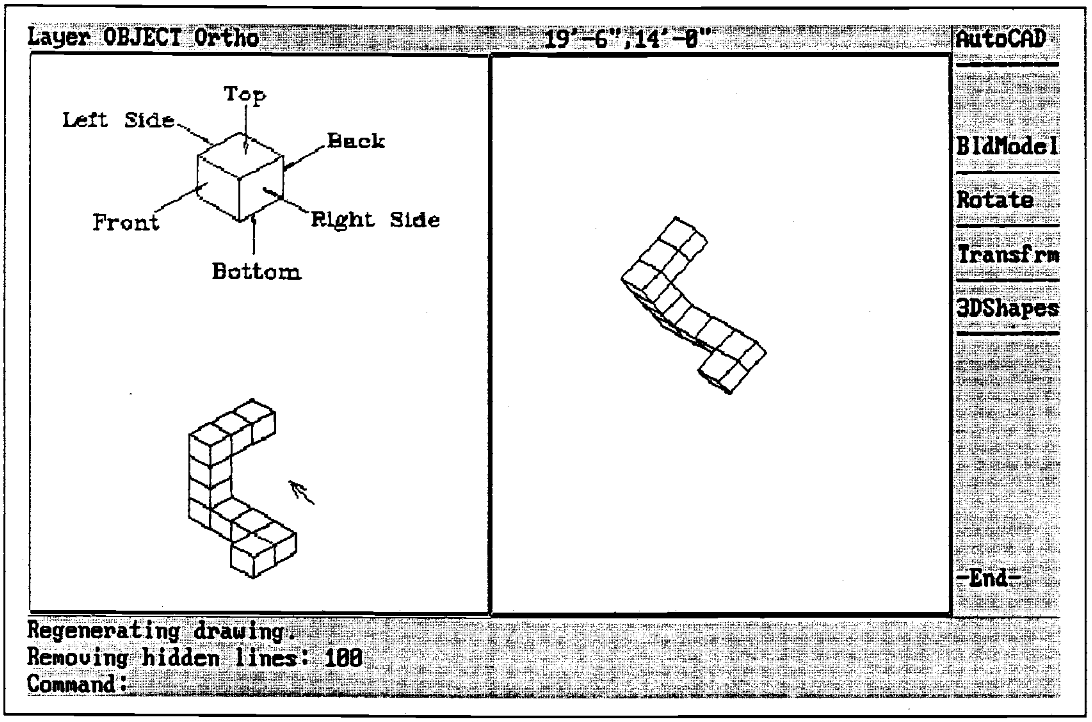
Select "Get Ready".

DO THIS



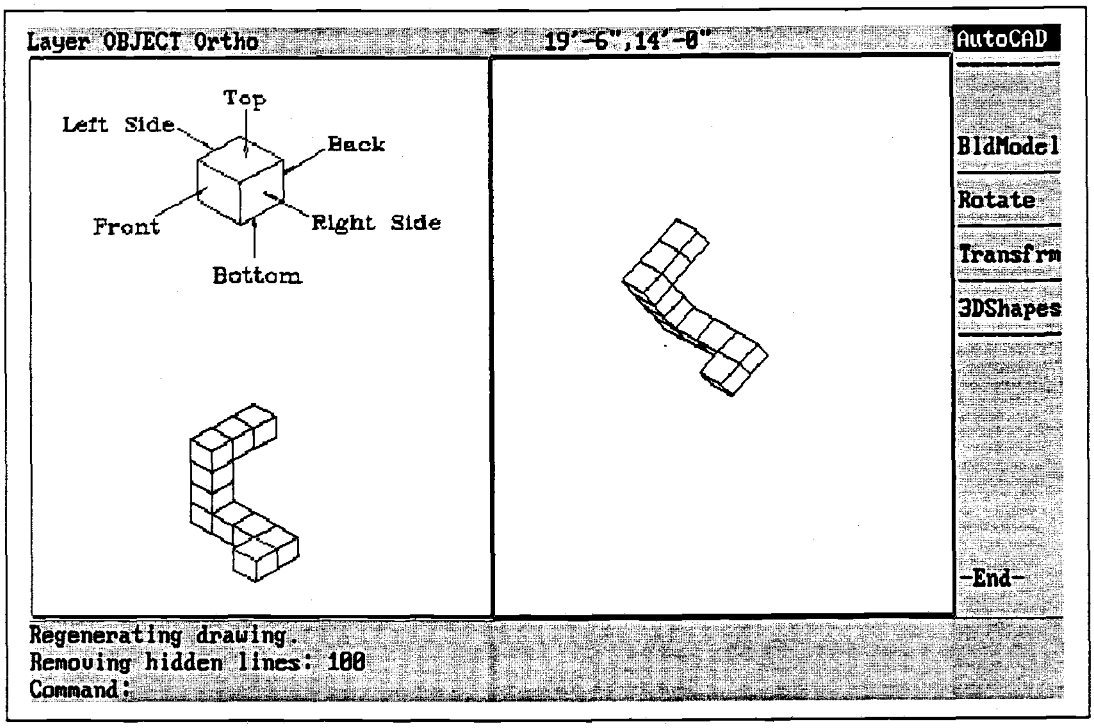
Select "Rotate +30".

DO THIS



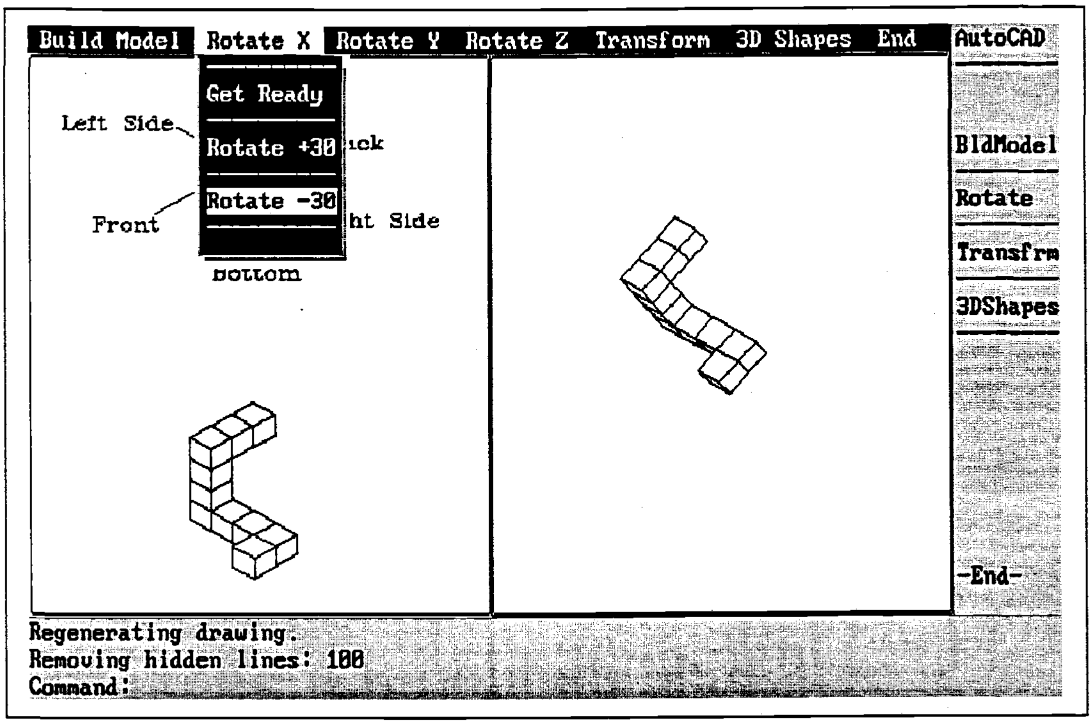
Your model has been rotated 30 degrees along the X axis.

JUST LOOK AND READ



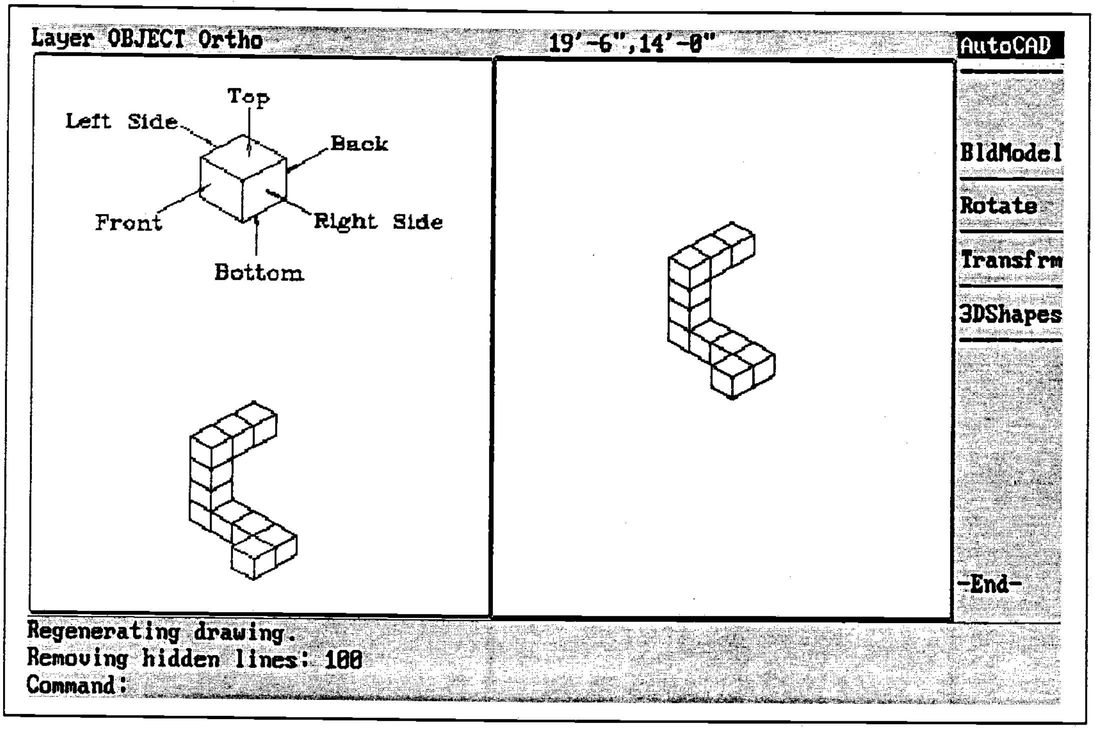
Can you imagine this model rotated back? Will it match the example?

JUST LOOK AND READ



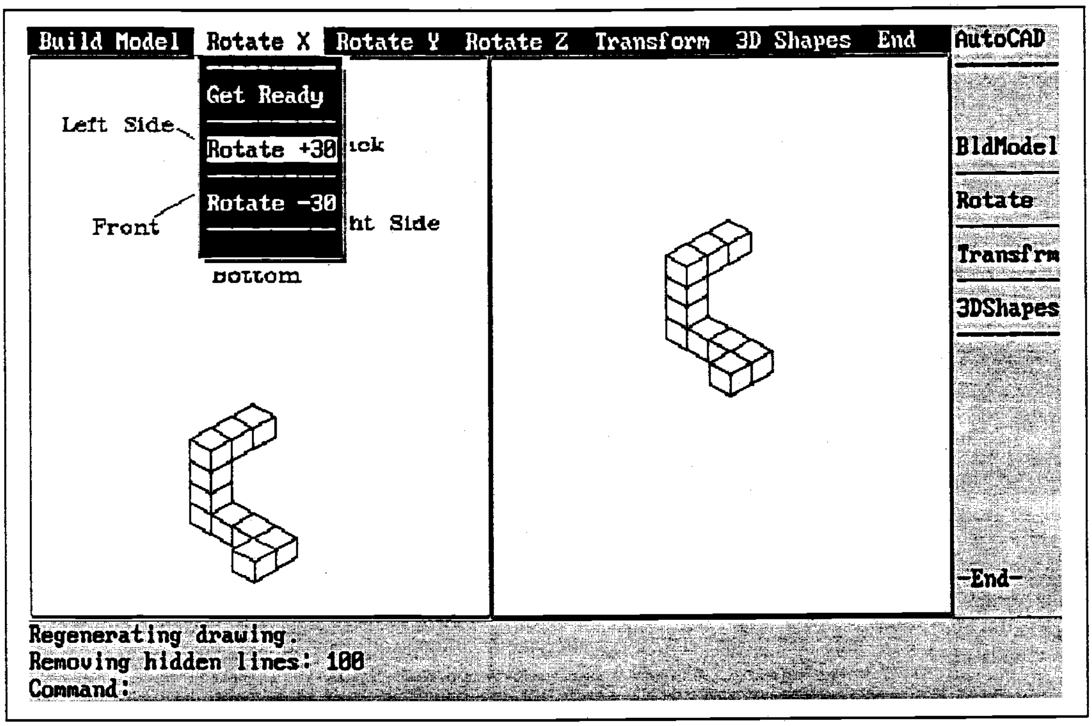
Let's do it with the computer. Select "Rotate X" and "Rotate -30".

DO THIS



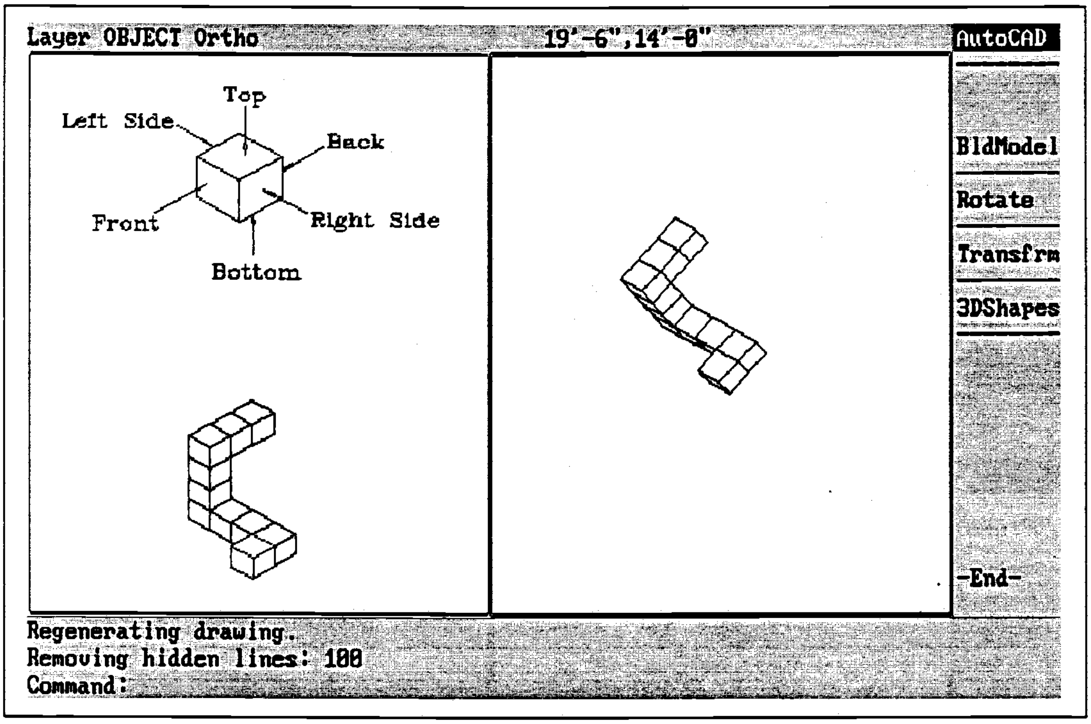
The model is rotated back to its original position.

JUST LOOK AND READ



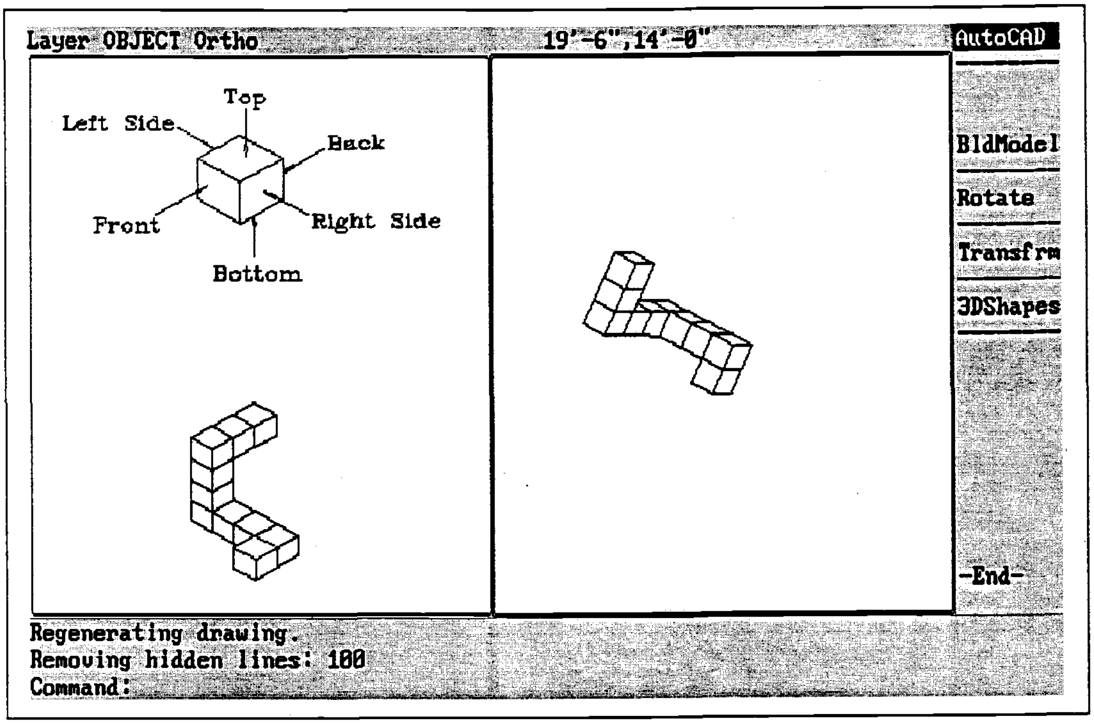
Continue to rotate at +30. Go around until it matches the example.

DO THIS



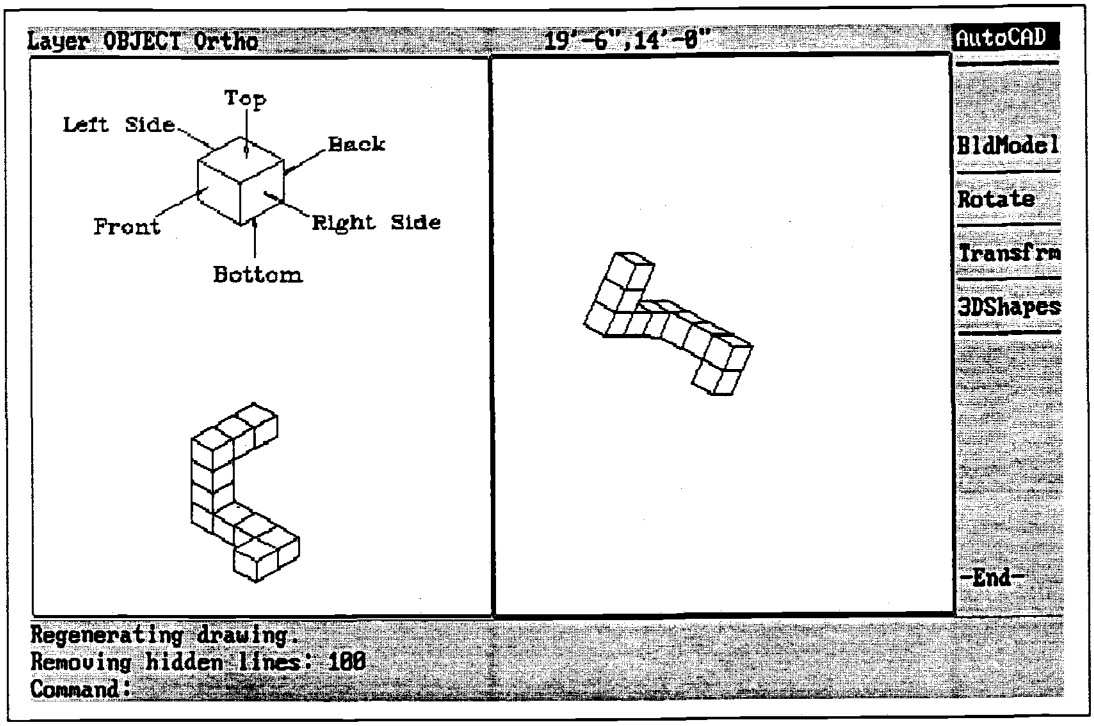
This is +30 degrees.

JUST LOOK AND READ



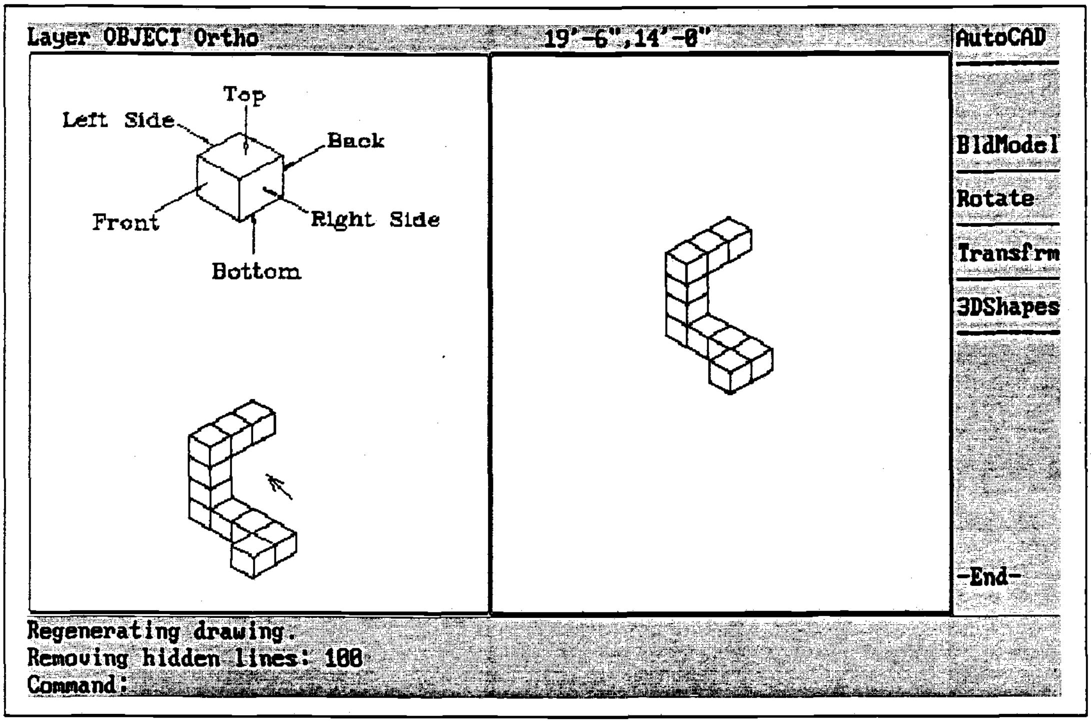
This is +30 degrees more. Can you imagine the model rotated back.

DO THIS



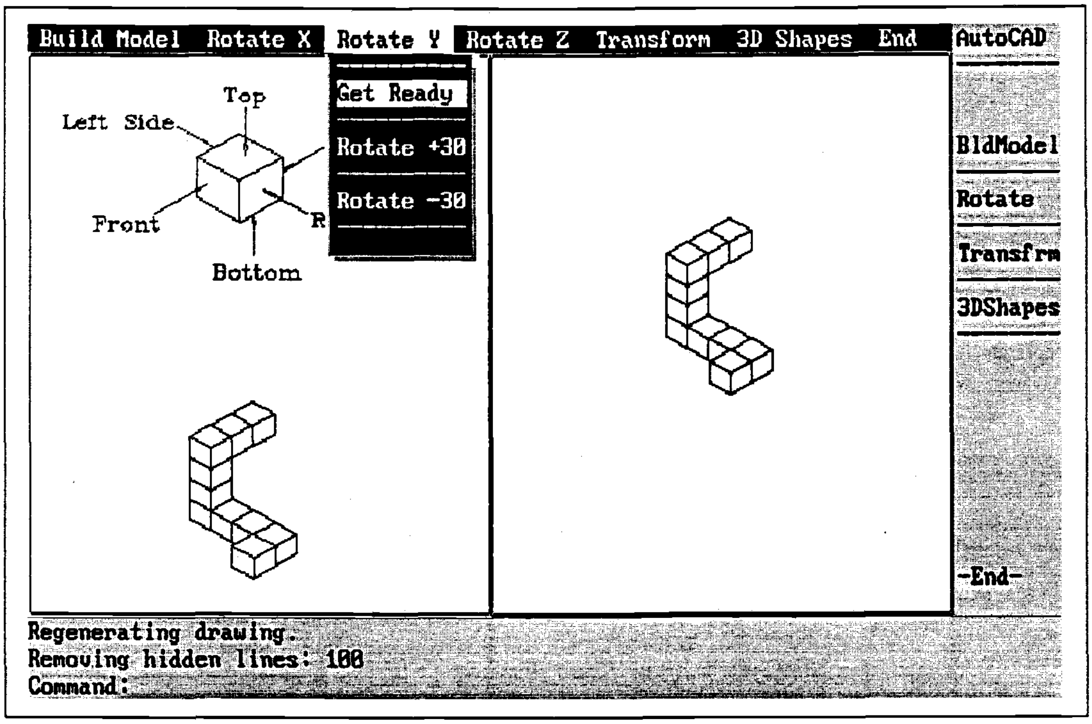
Now continue. See if you can imagine the model rotated back each time.

DO THIS



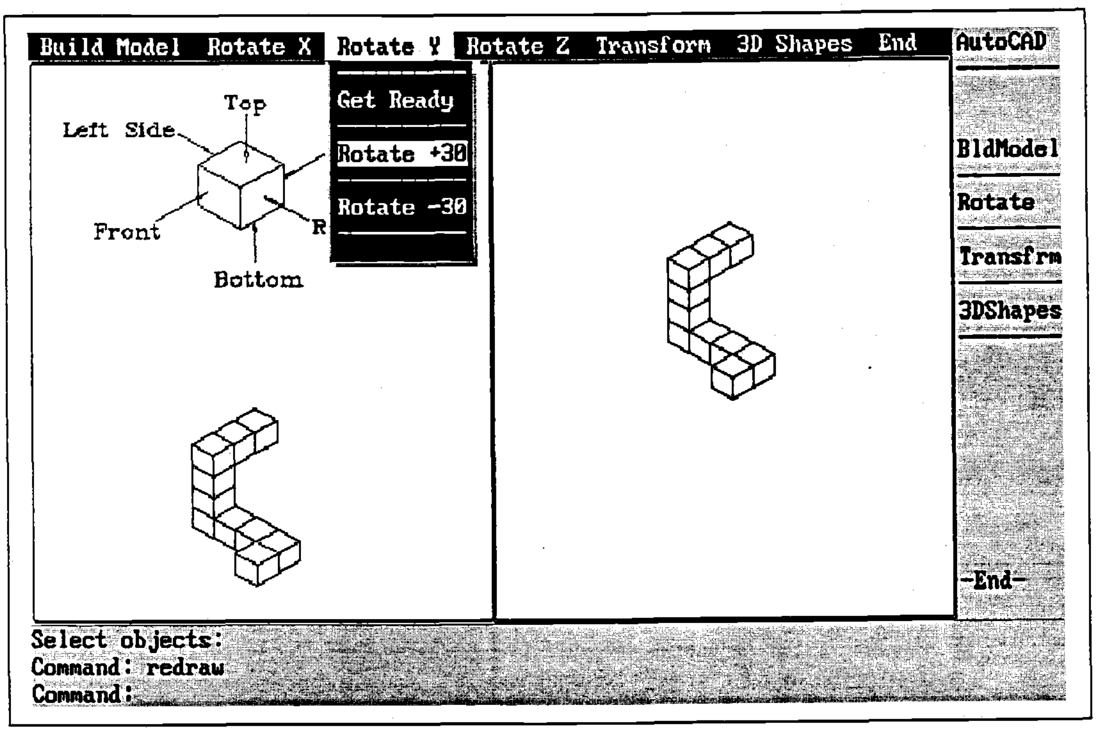
After completing the X rotations, your model should look like this.

JUST LOOK AND READ



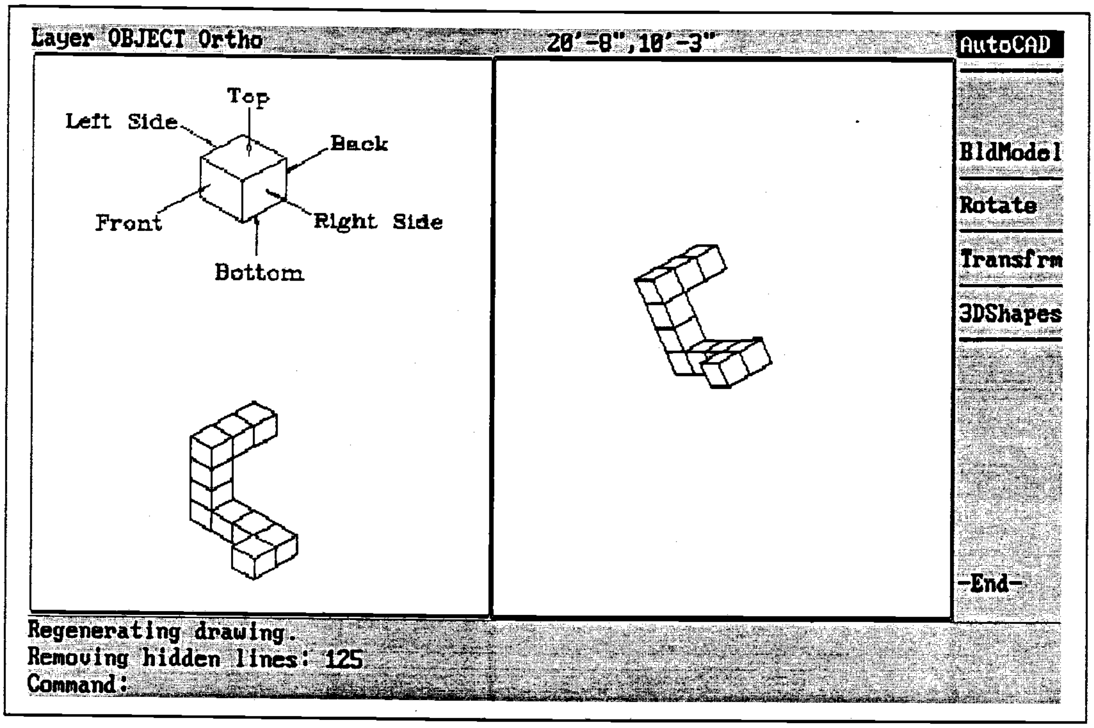
Now, rotate the model on the Y axis. Select "Get Ready".

DO THIS



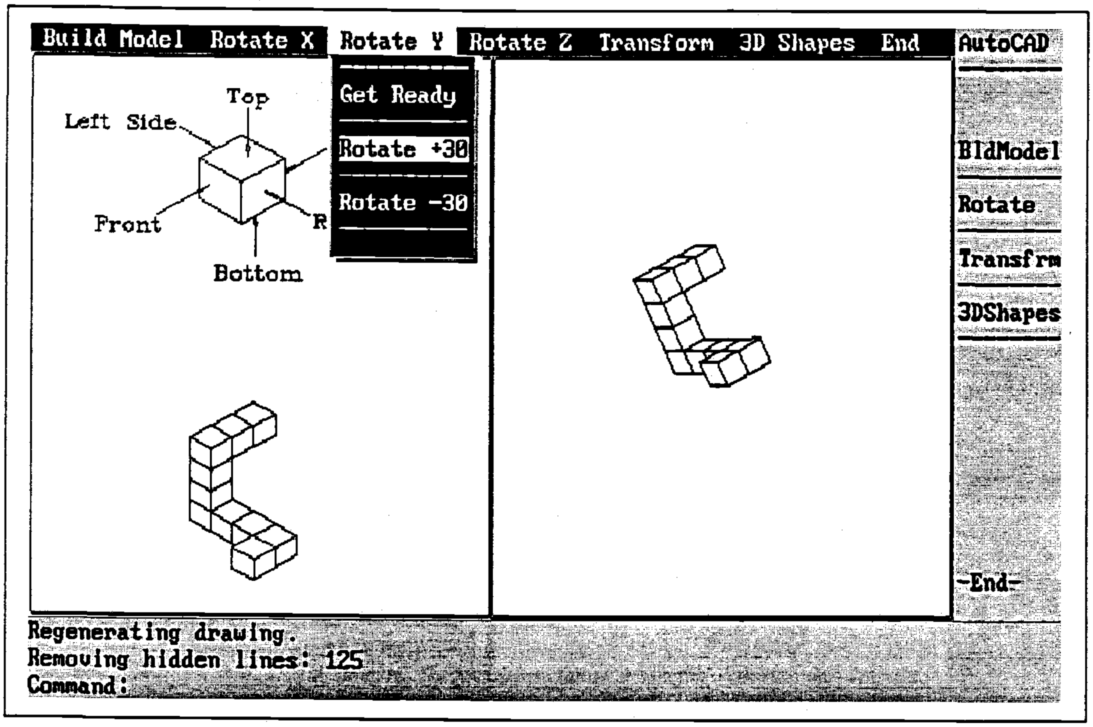
Select "Rotate +30".

DO THIS



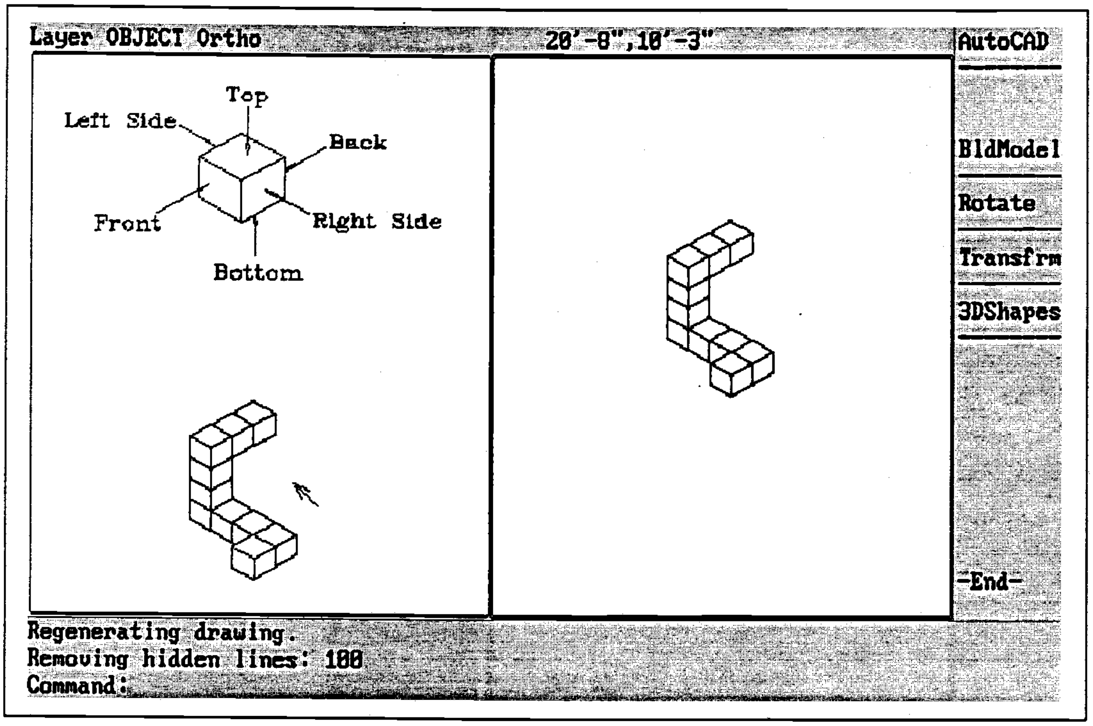
The model is rotated +30 on the Y axis. Imagine it rotated back.

JUST LOOK AND READ



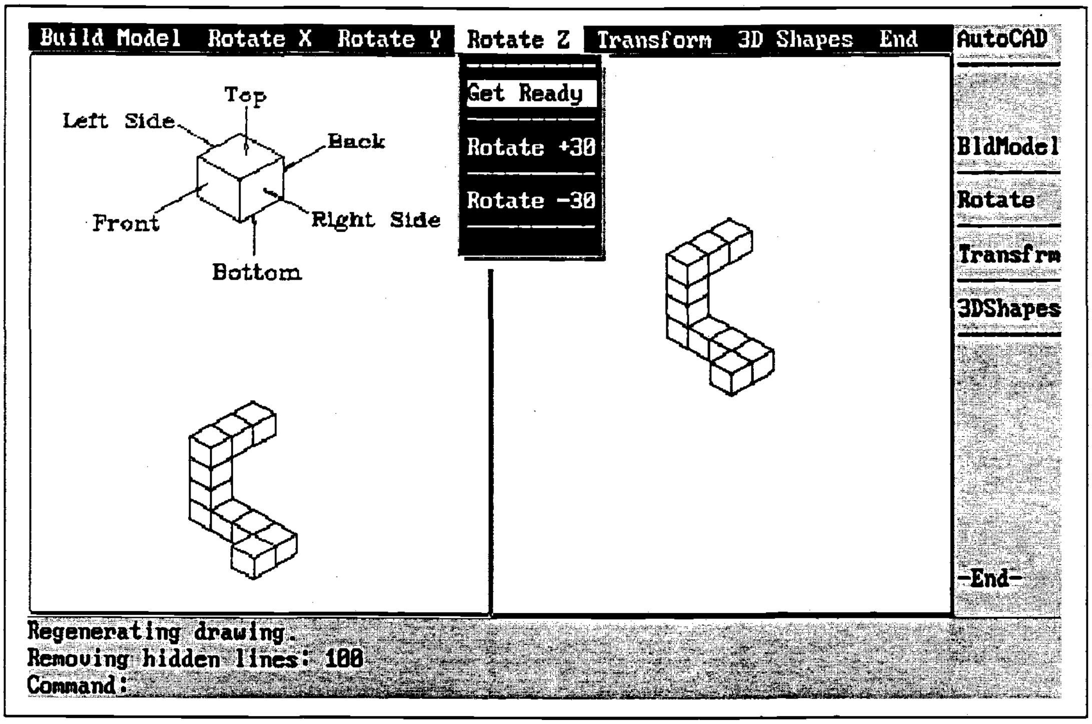
Continue rotating it +30. Imagine it rotated back each time.

DO THIS



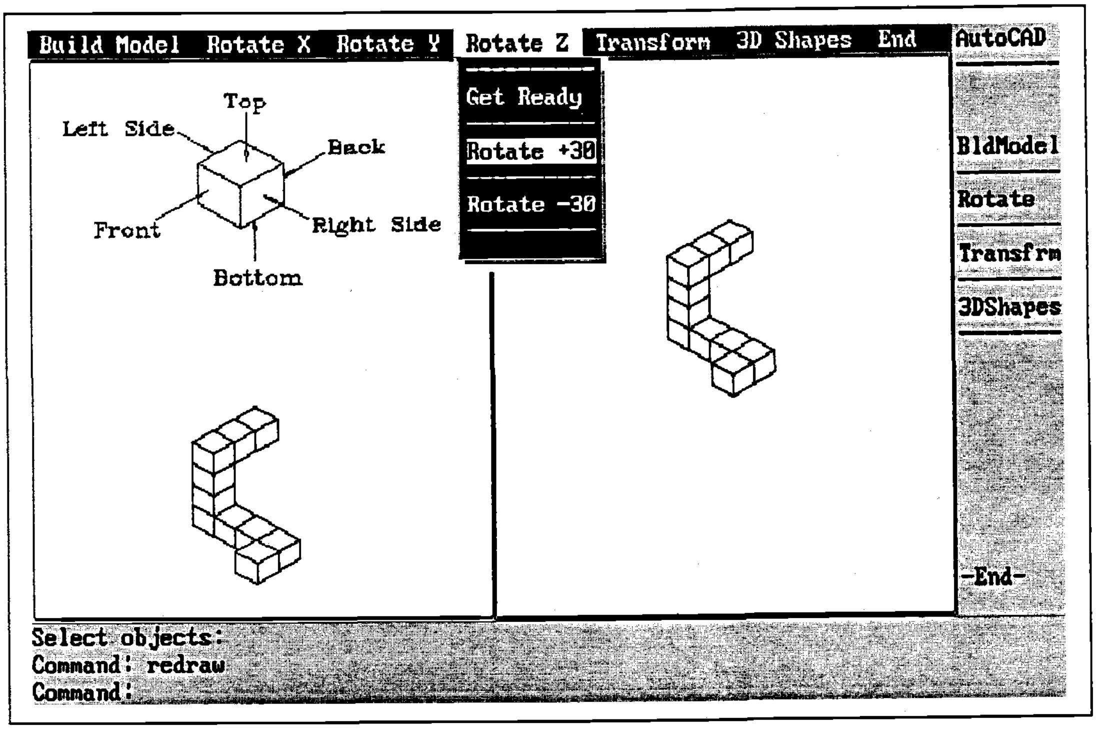
When it is rotated back to its original position, it looks like this.

JUST LOOK AND READ



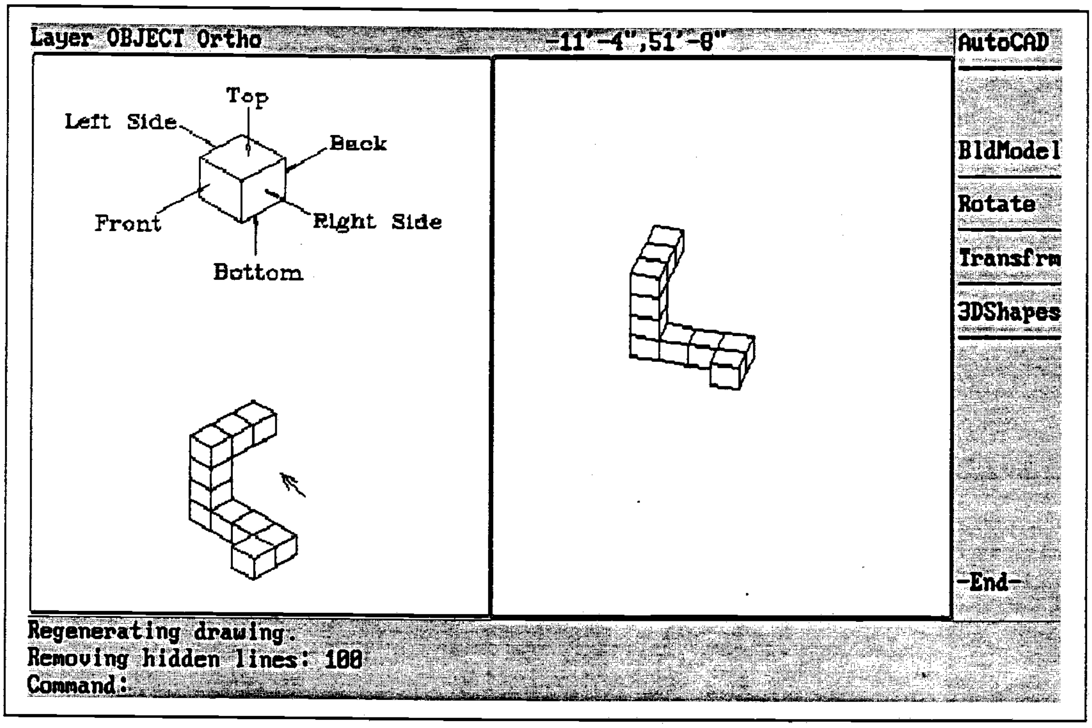
Now, rotate the model about the Z axis. Select "Get Ready".

DO THIS



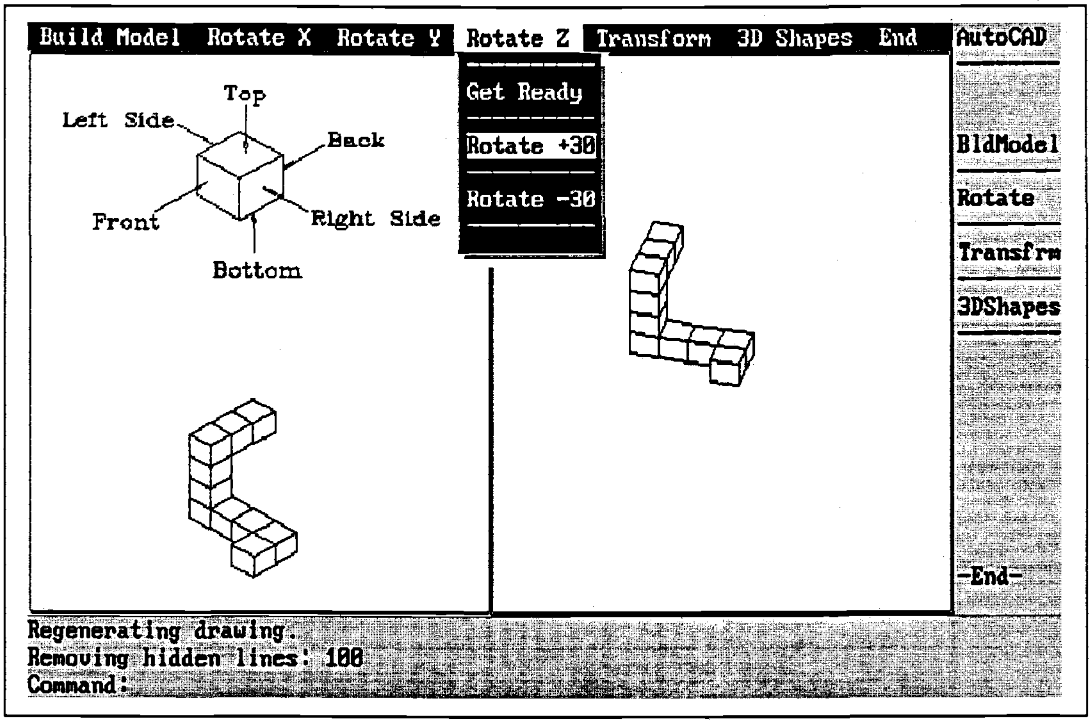
Rotate the model +30. Select "Rotate +30".

DO THIS



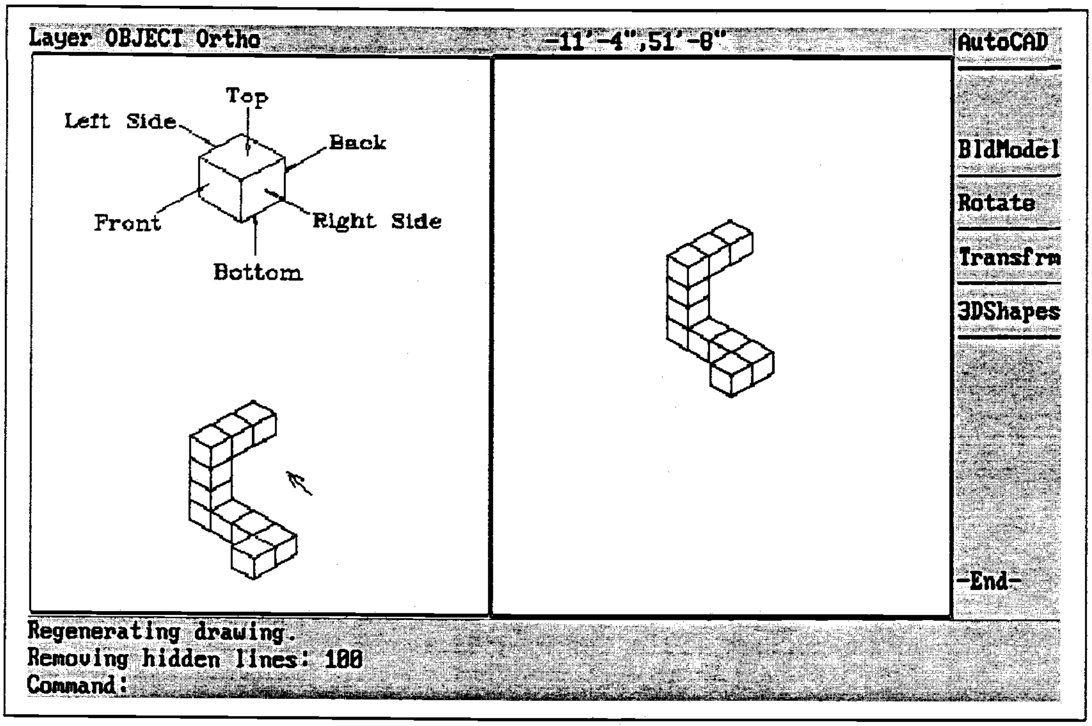
The model is rotated about the Z axis. Imagine it rotated back.

JUST LOOK AND READ



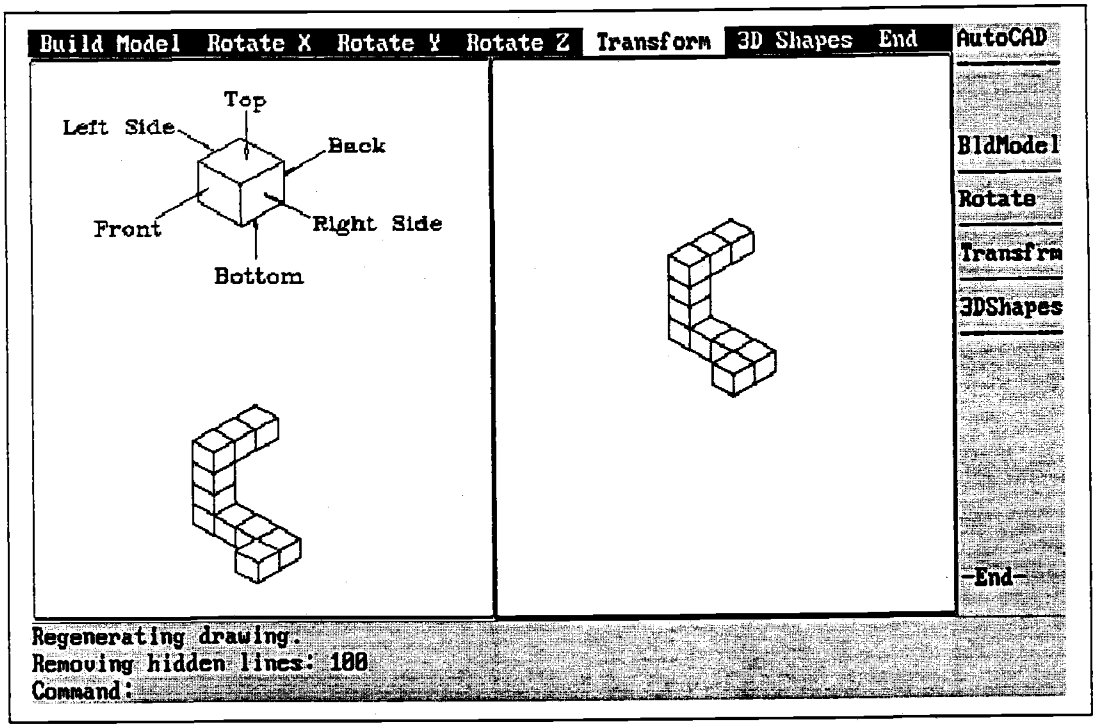
Continue rotating the model +30. Imagine it rotated back each time.

DO THIS



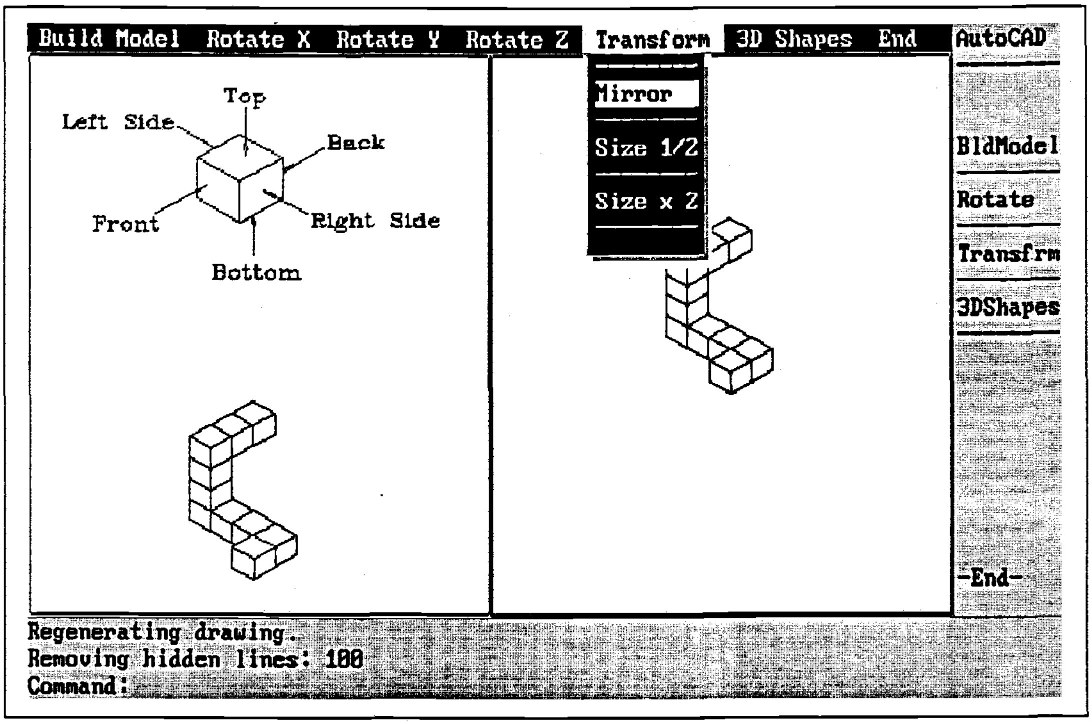
The model should now be back to its original position.

JUST LOOK AND READ



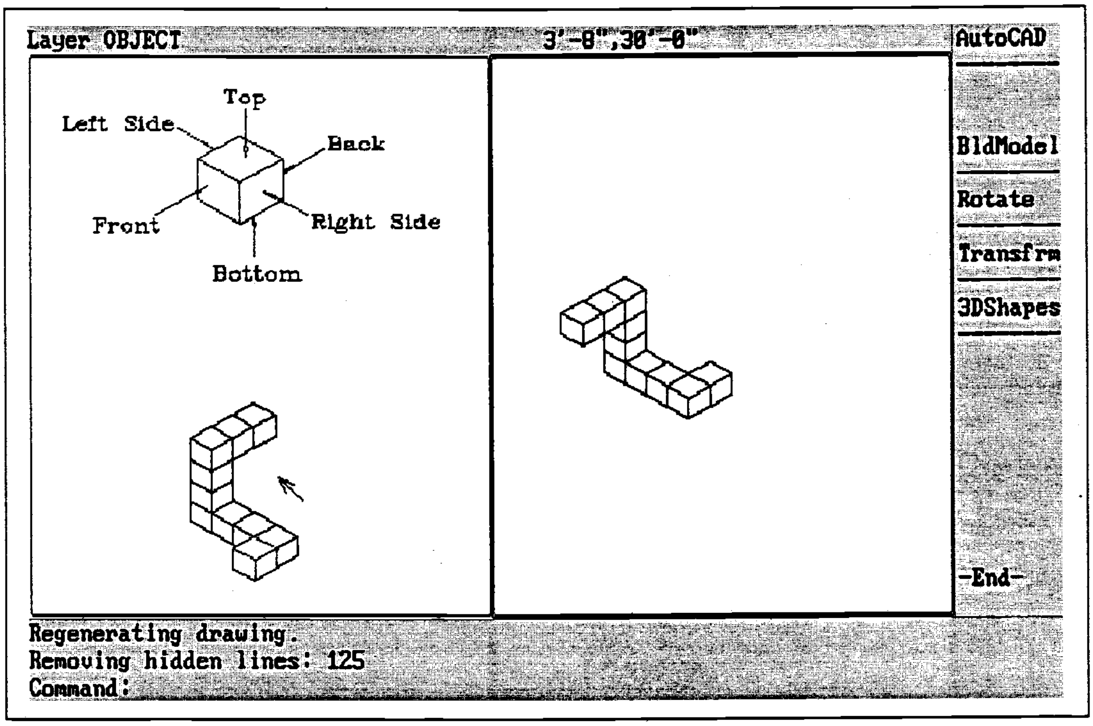
Now, select "Transform"

DO THIS



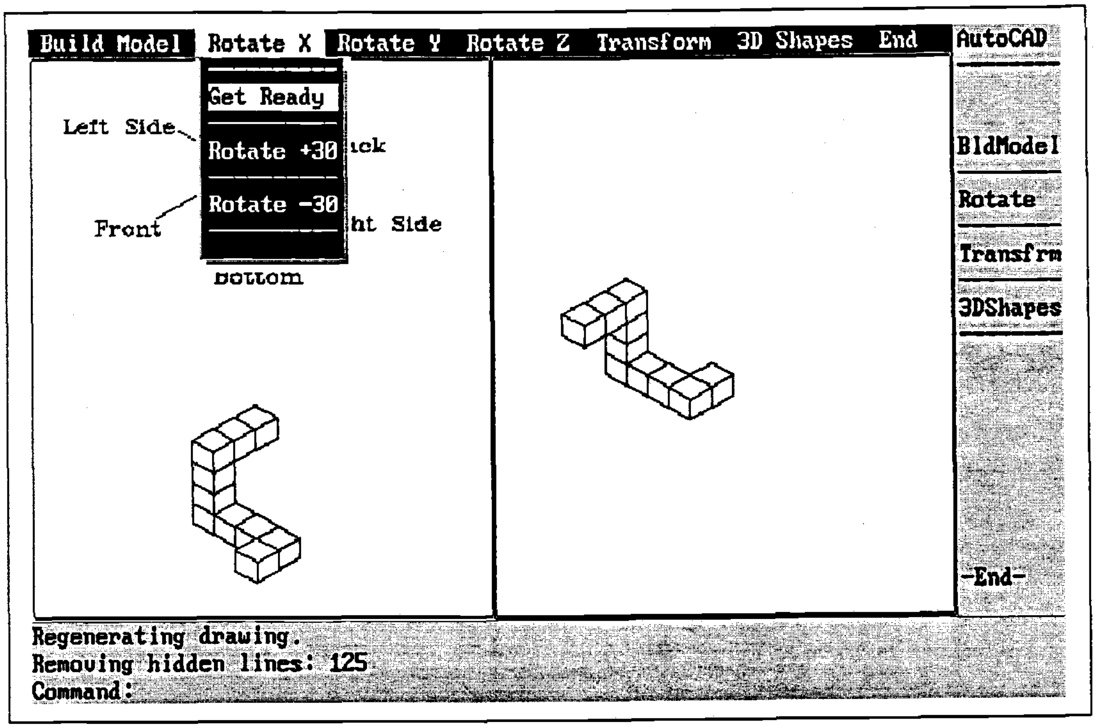
Select "Mirror".

DO THIS



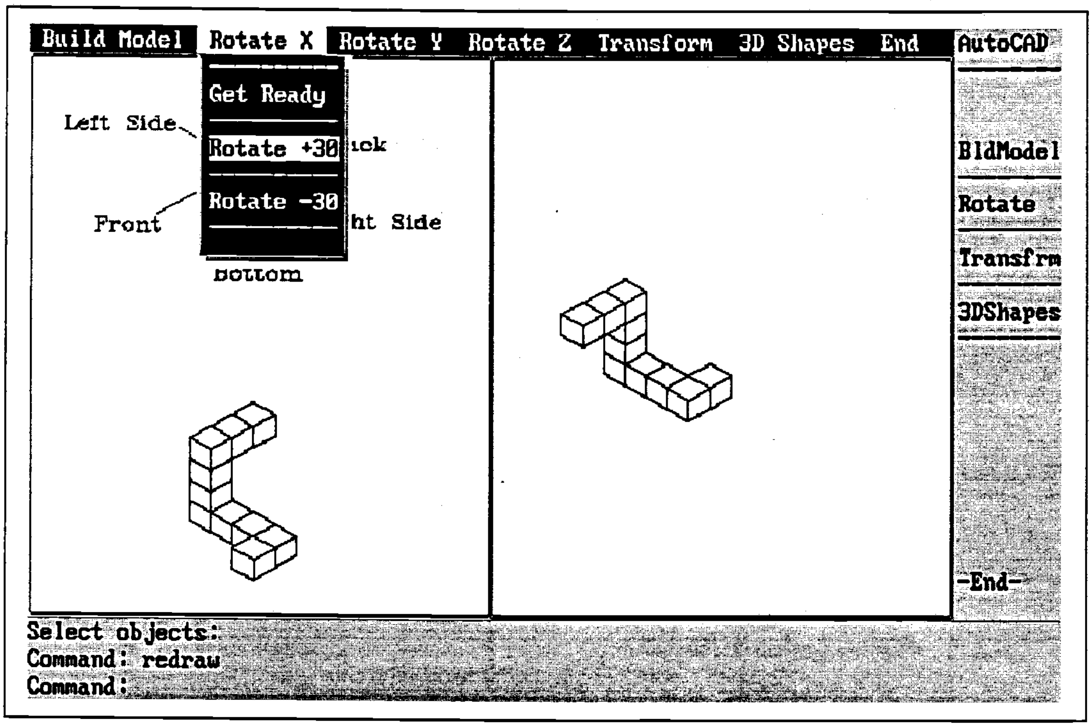
Your model is now a mirror image of the original. Compare to example.

JUST LOOK AND READ



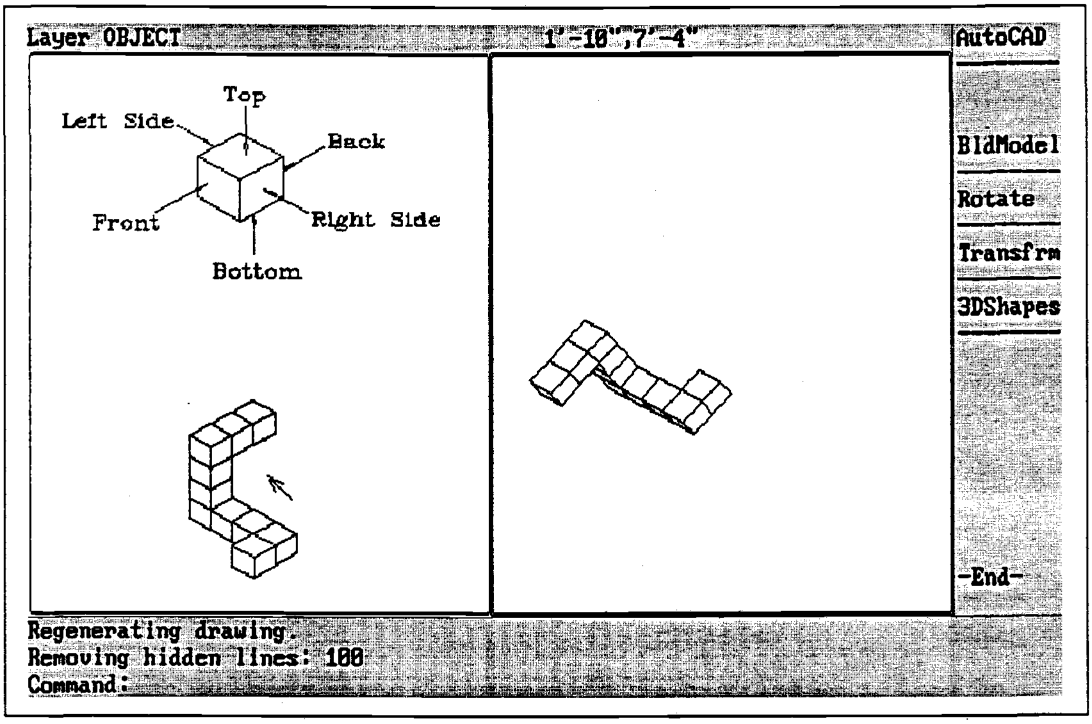
Let's rotate the mirror image about the X axis. Select "Get Ready".

DO THIS



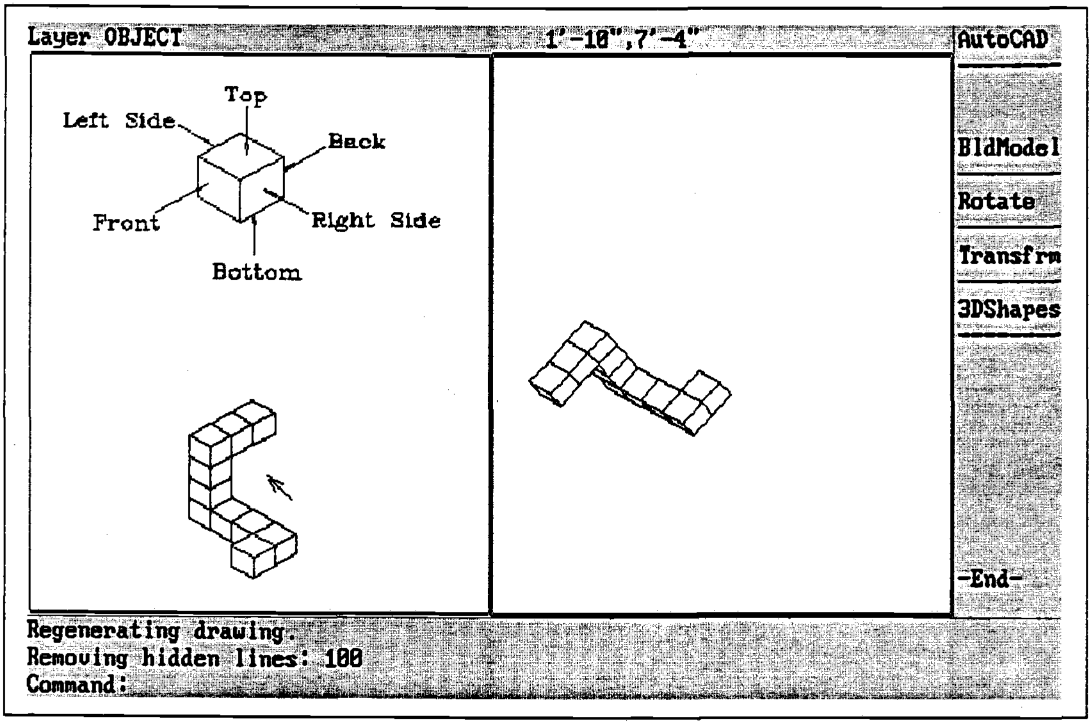
Select "Rotate +30".

DO THIS



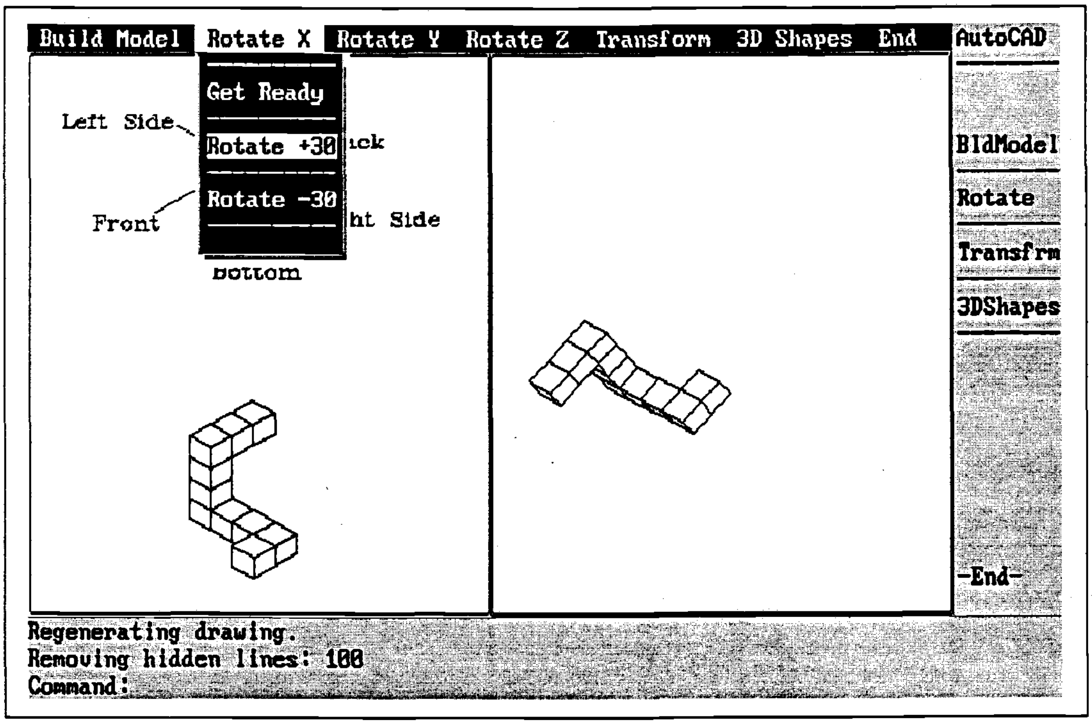
Can you imagine the model rotated to match the example?

JUST LOOK AND READ



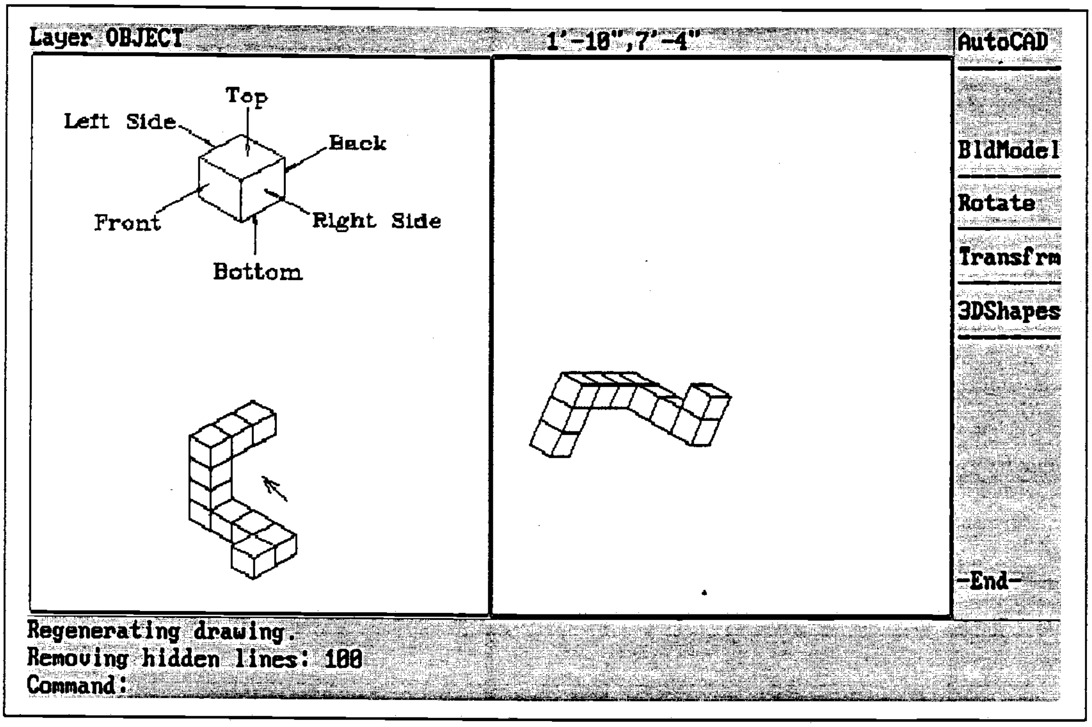
If you said NO, that's correct. A mirror image can not match.

JUST LOOK AND READ



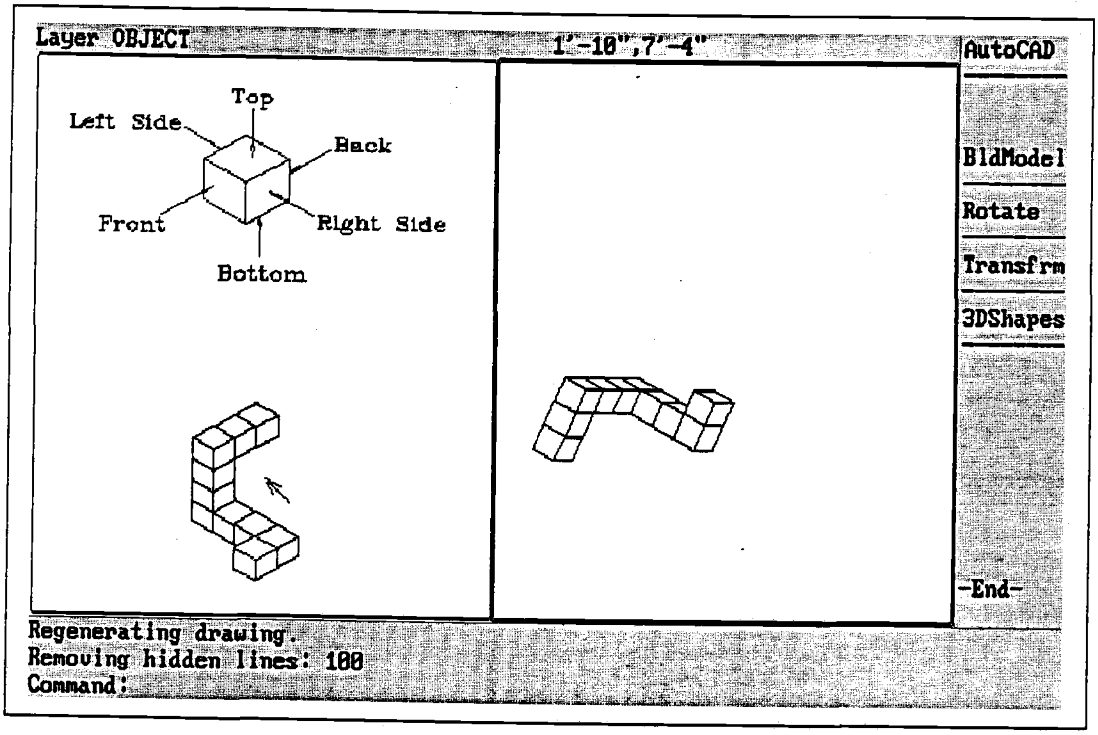
Rotate the model +30 again.

DO THIS



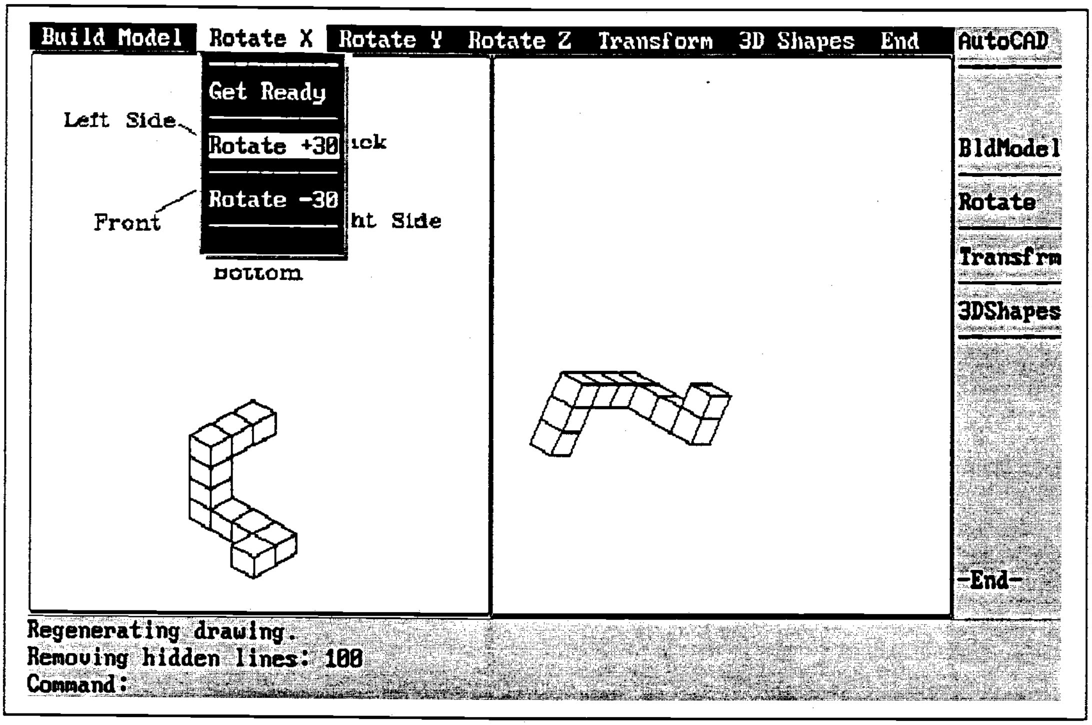
Try it again. Imagine the model rotated. Can it match the example?

JUST LOOK AND READ



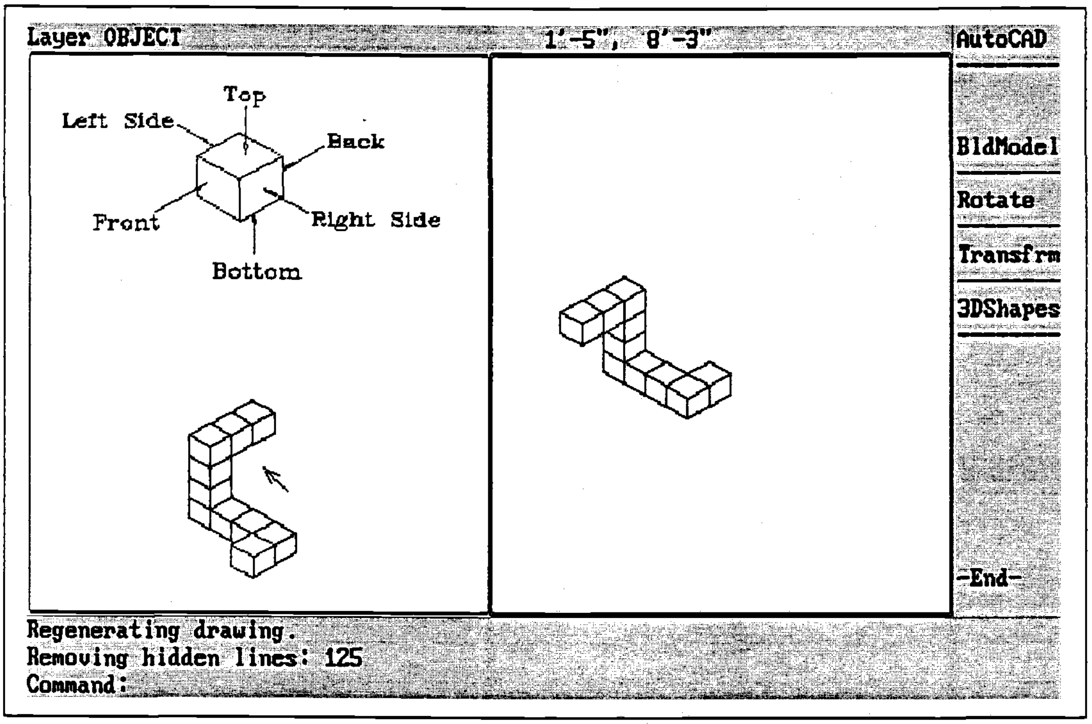
No it can not. Just like before, a mirror image can not match.

JUST LOOK AND READ



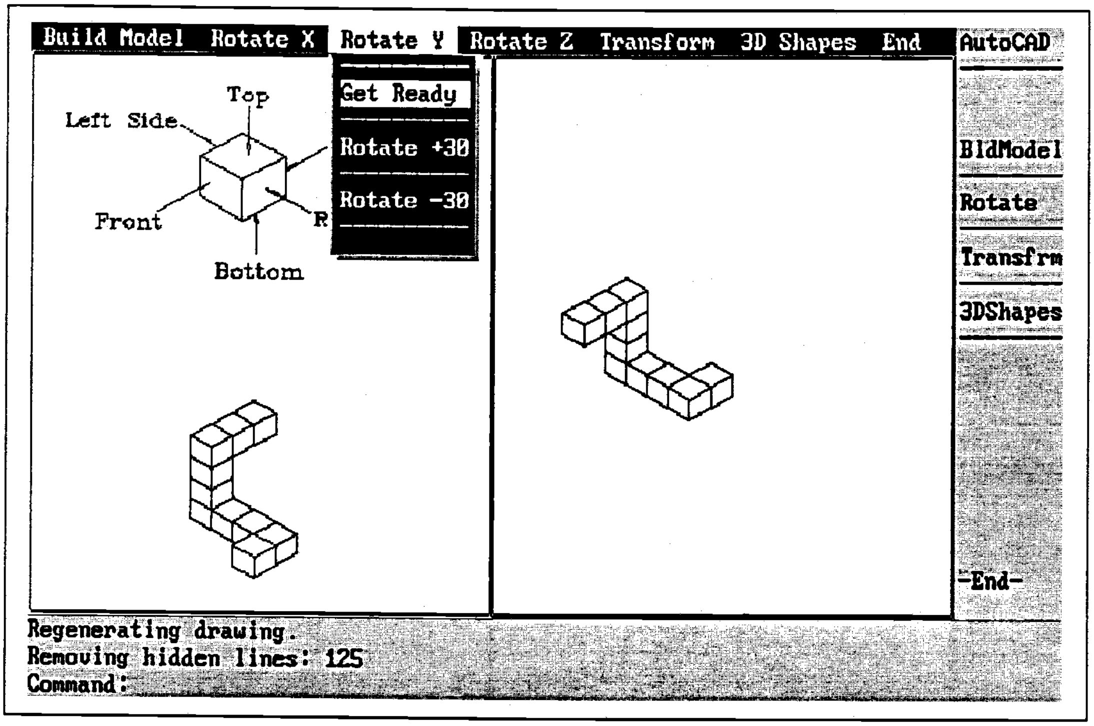
Continue to rotate the model about the X axis. Does it match example?

DO THIS



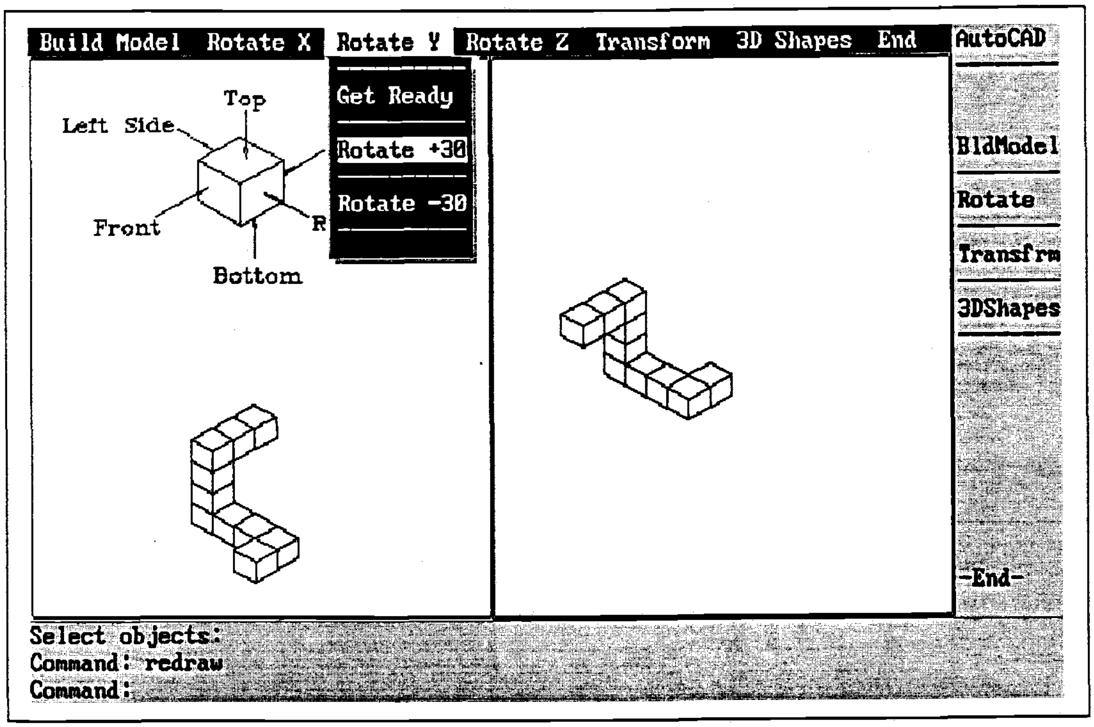
Your model should now look like this.

JUST LOOK AND READ



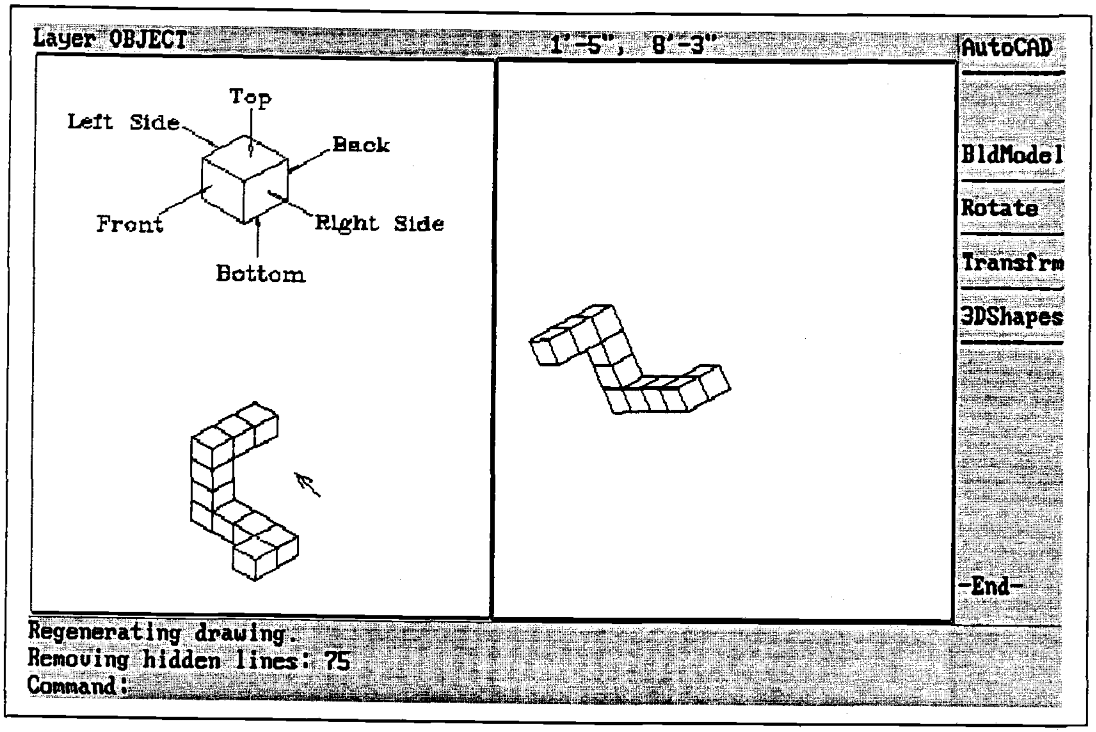
Now rotate the model about the Y axis. Select "Get Ready".

DO THIS



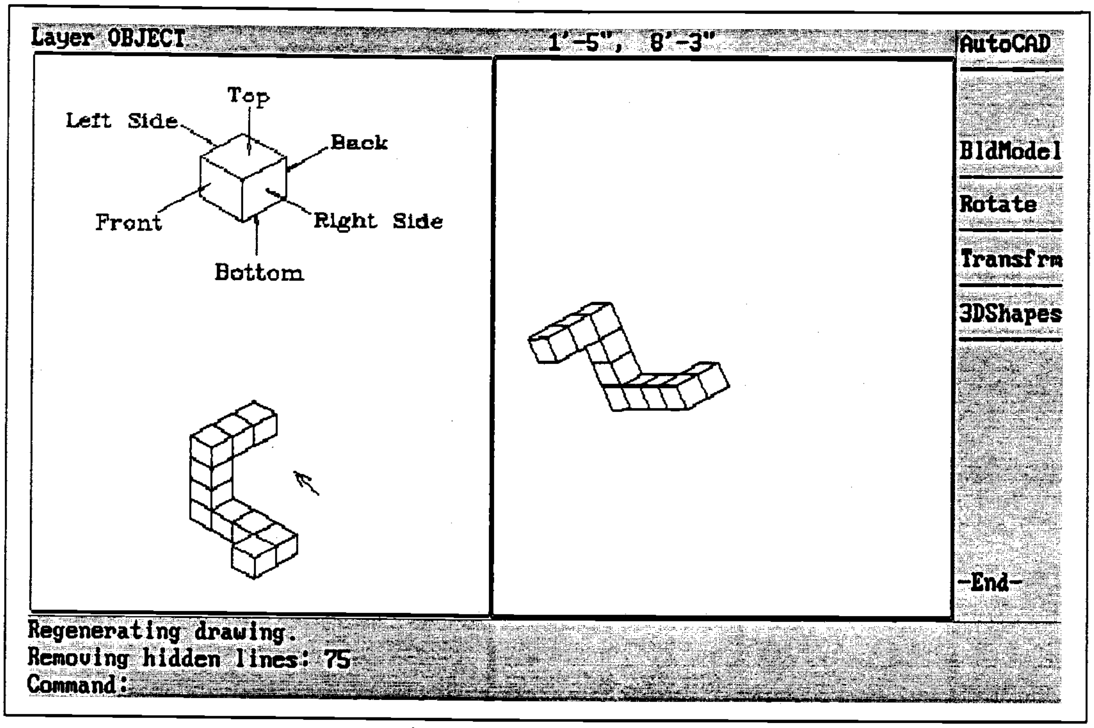
Select "Rotate +30".

DO THIS



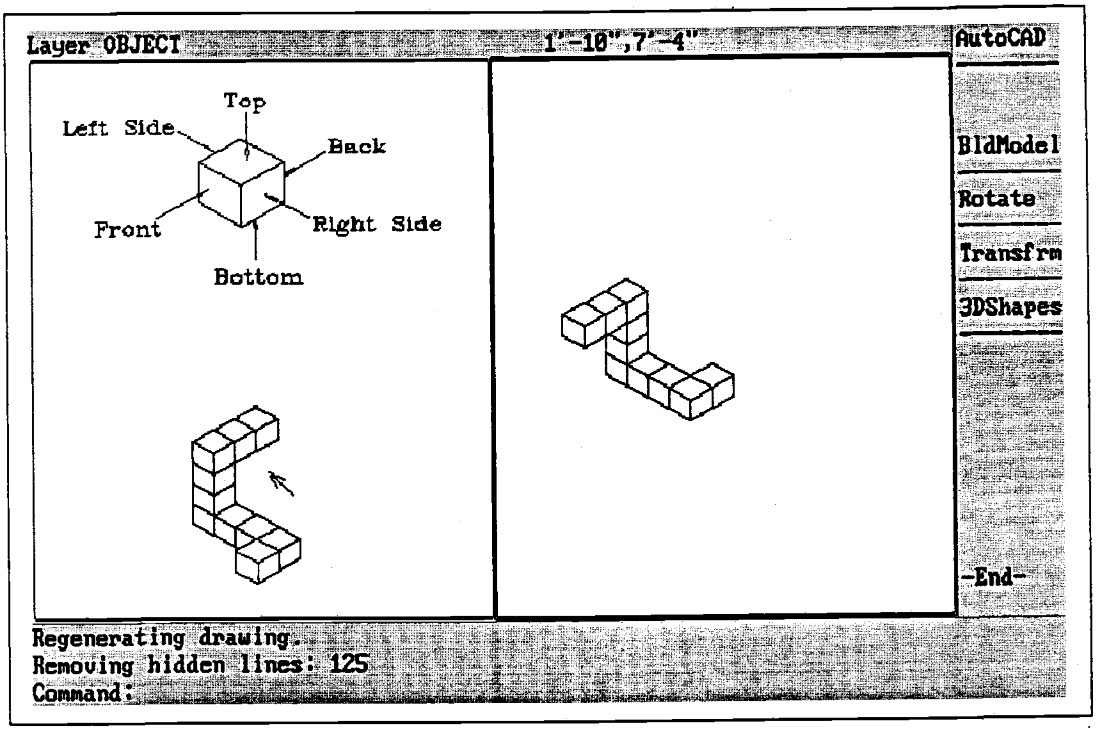
Can the model be rotated to match the example? Try and imagine it.

JUST LOOK AND READ



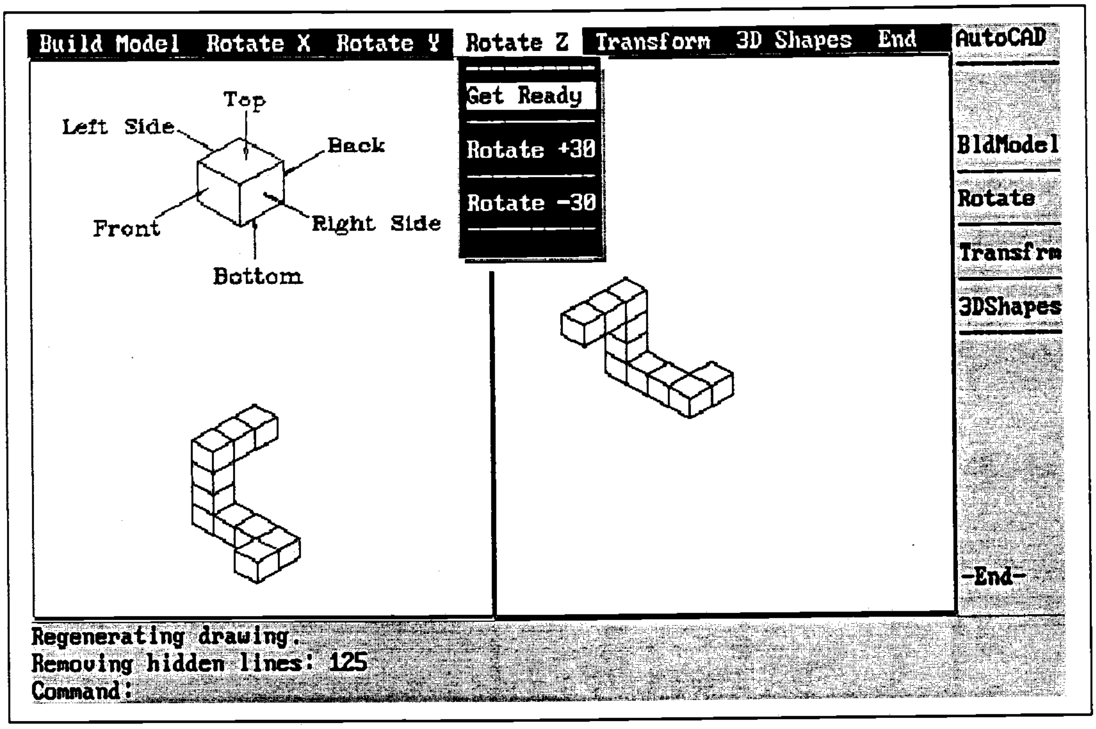
No it can not. Continue rotating the model until back to original.

DO THIS



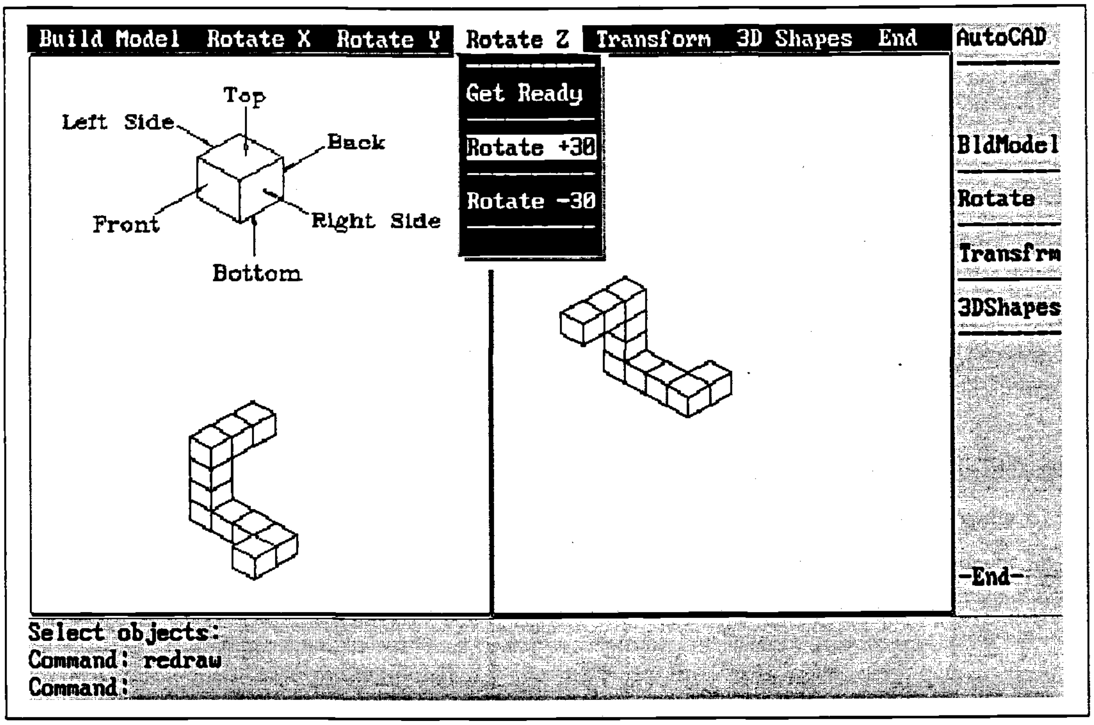
Rotate the model back to its original position. Like this.

DO THIS



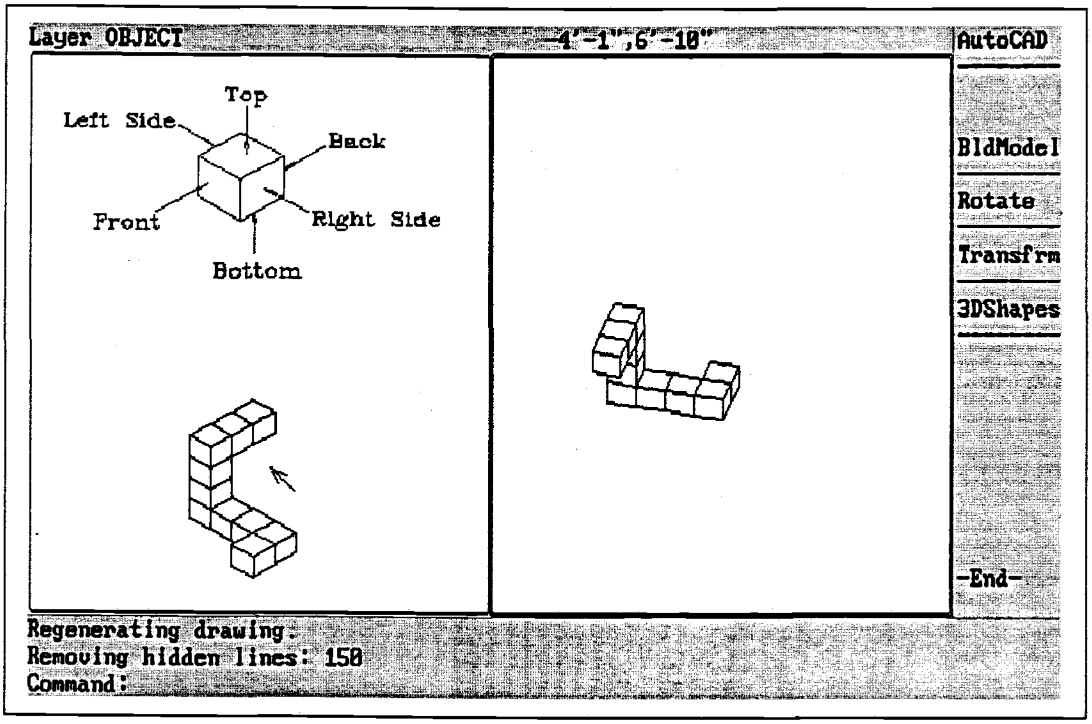
Now let's rotate the model on the Z axis. Select "Get Ready".

DO THIS



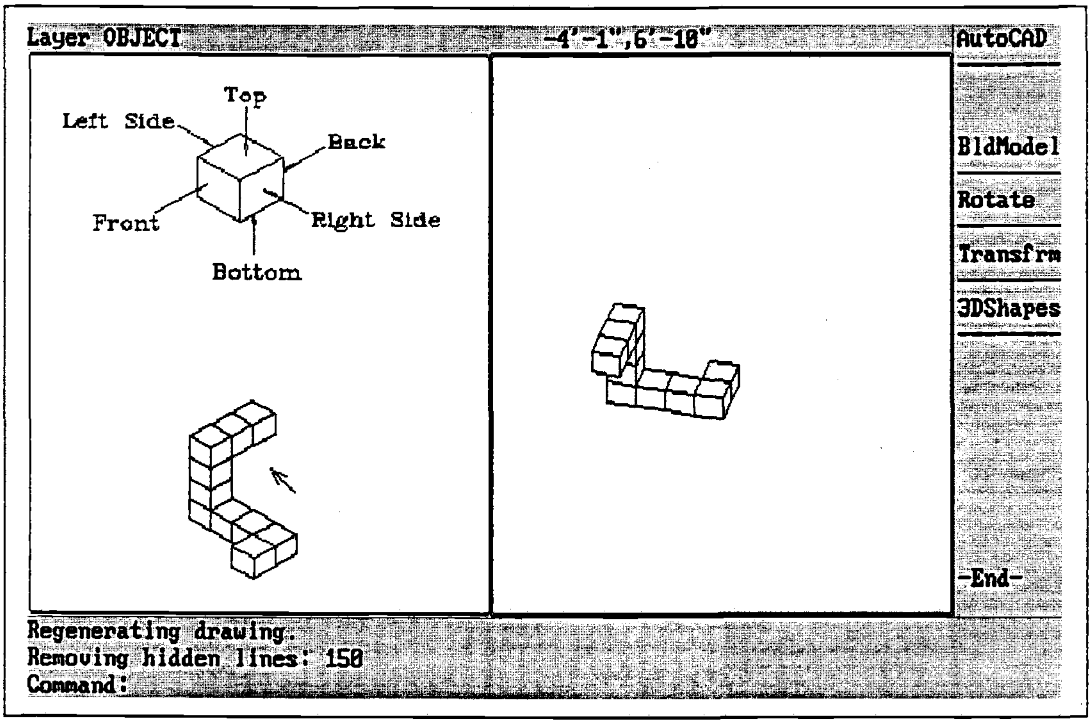
Select "Rotate +30".

DO THIS



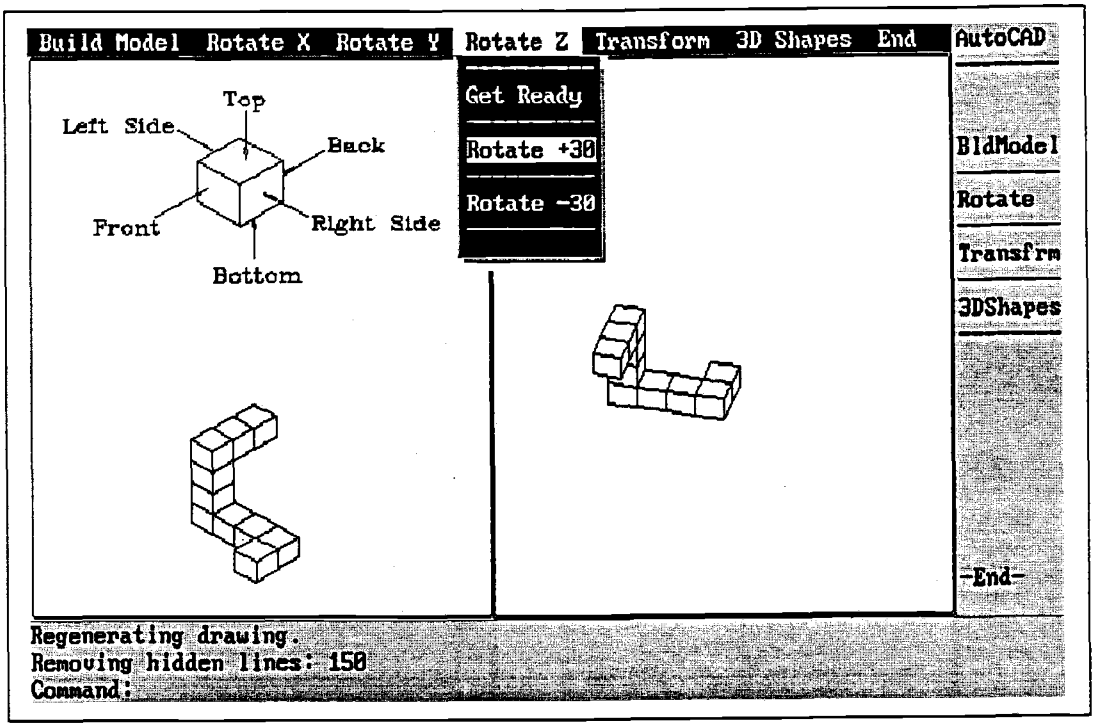
Try it again. Can the model be rotated to match the example?

JUST LOOK AND READ



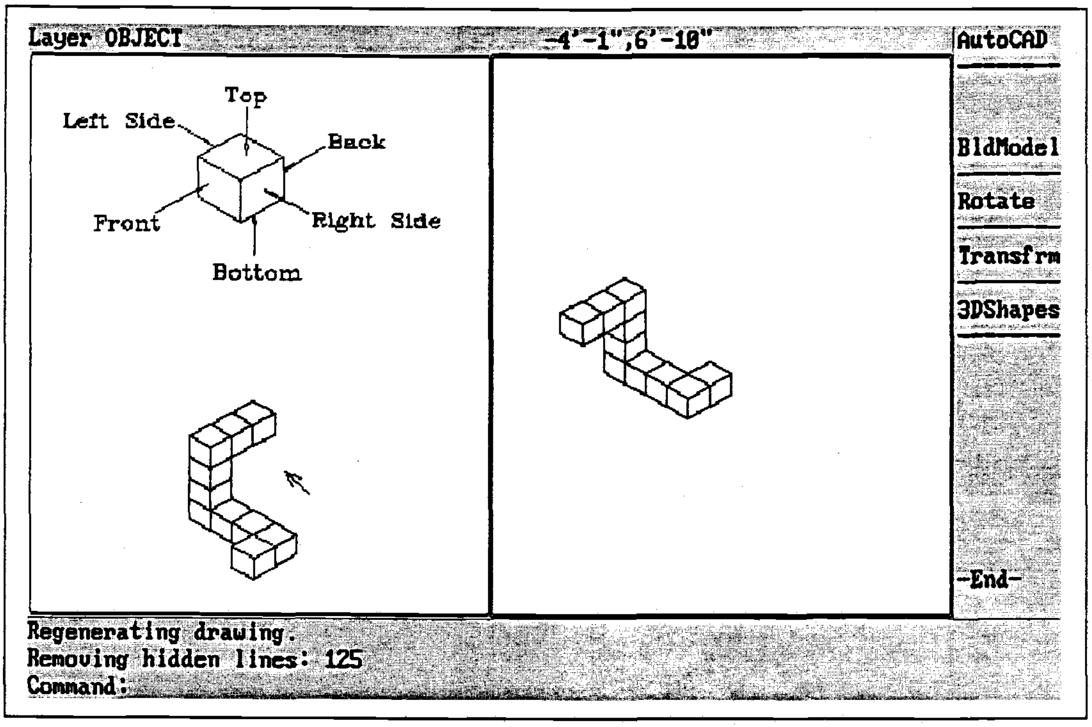
If you said NO, that's great. The mirror image can not match example.

JUST LOOK AND READ



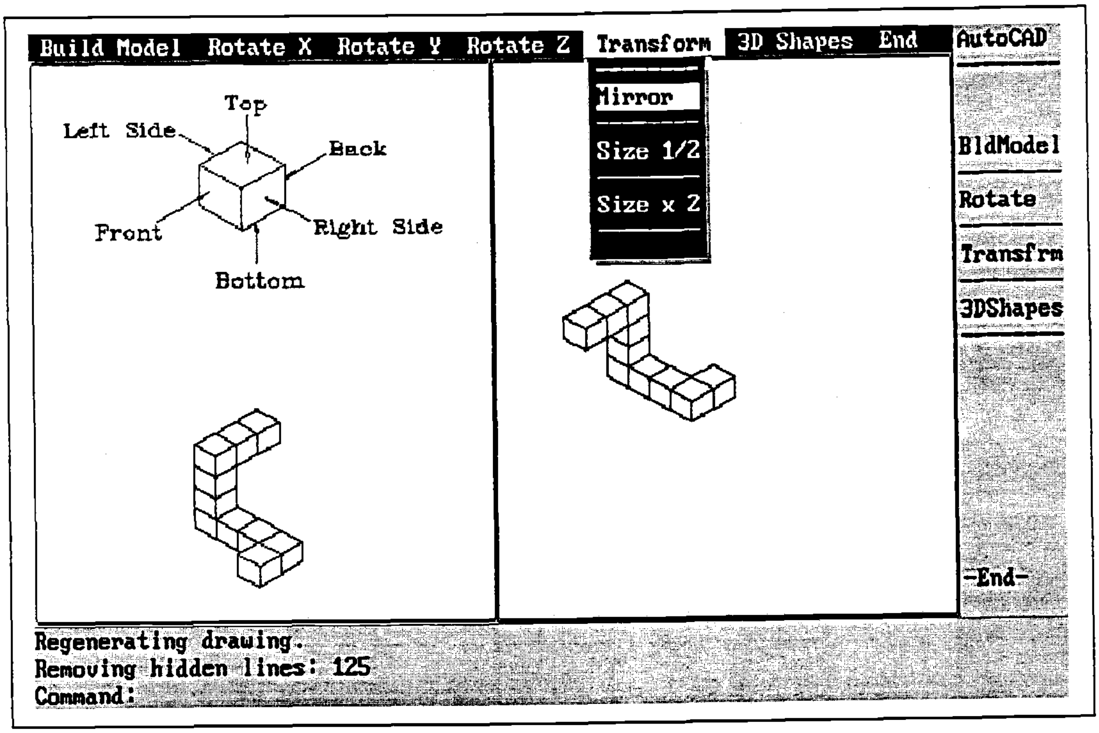
Continue rotating the mirror model about the Z axis.

DO THIS



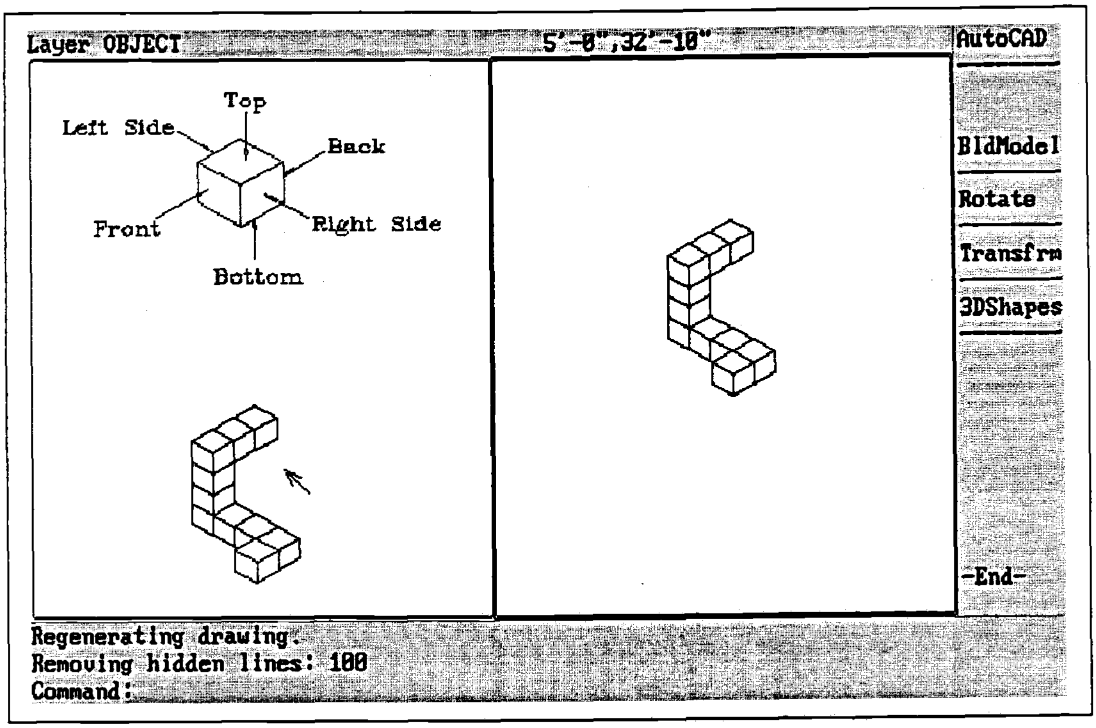
Your mirror model should now look like this.

JUST LOOK AND READ



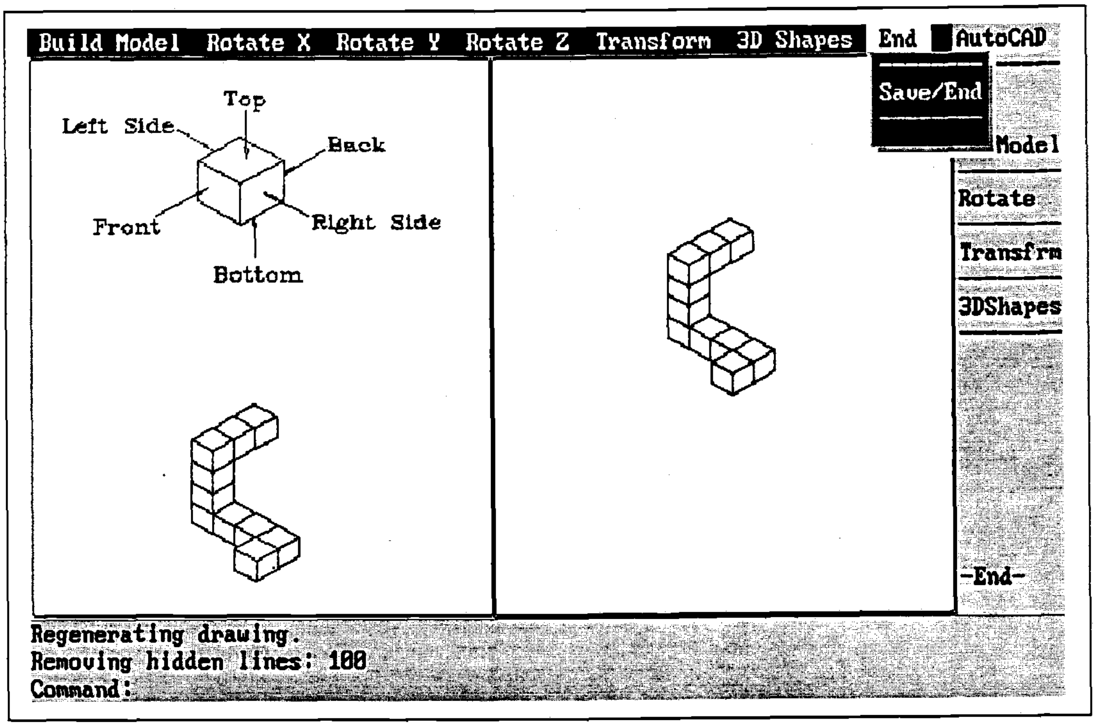
Let's mirror the model back to match the example. Select "Mirror".

DO THIS



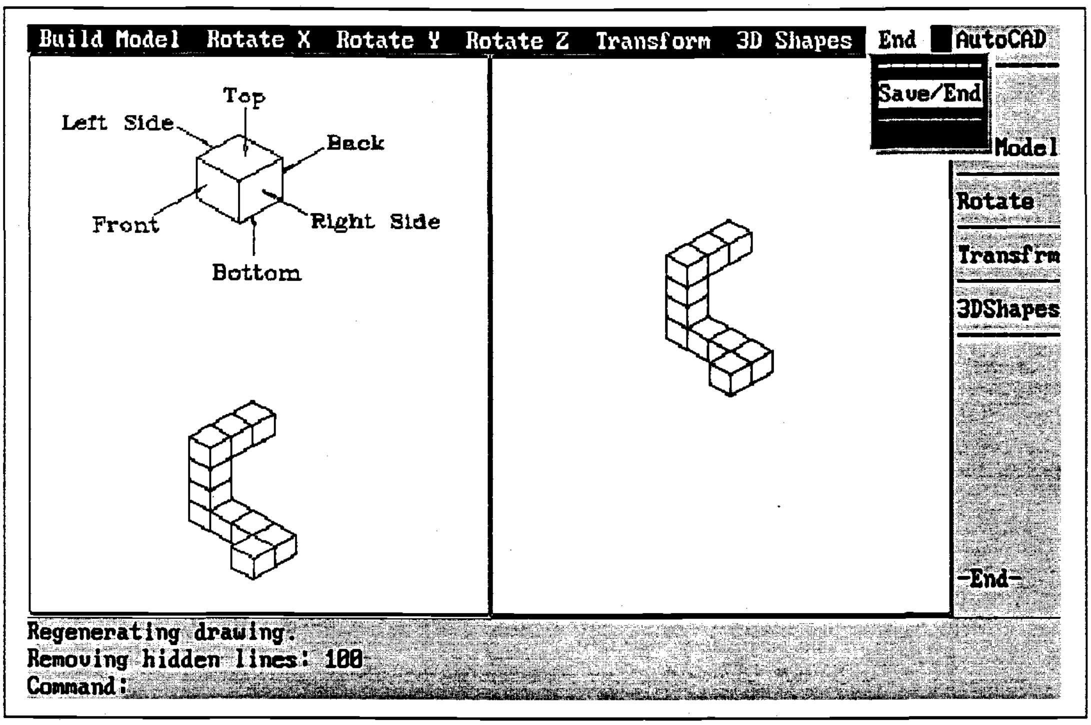
Your model should now match the example. Does it?

JUST LOOK AND READ



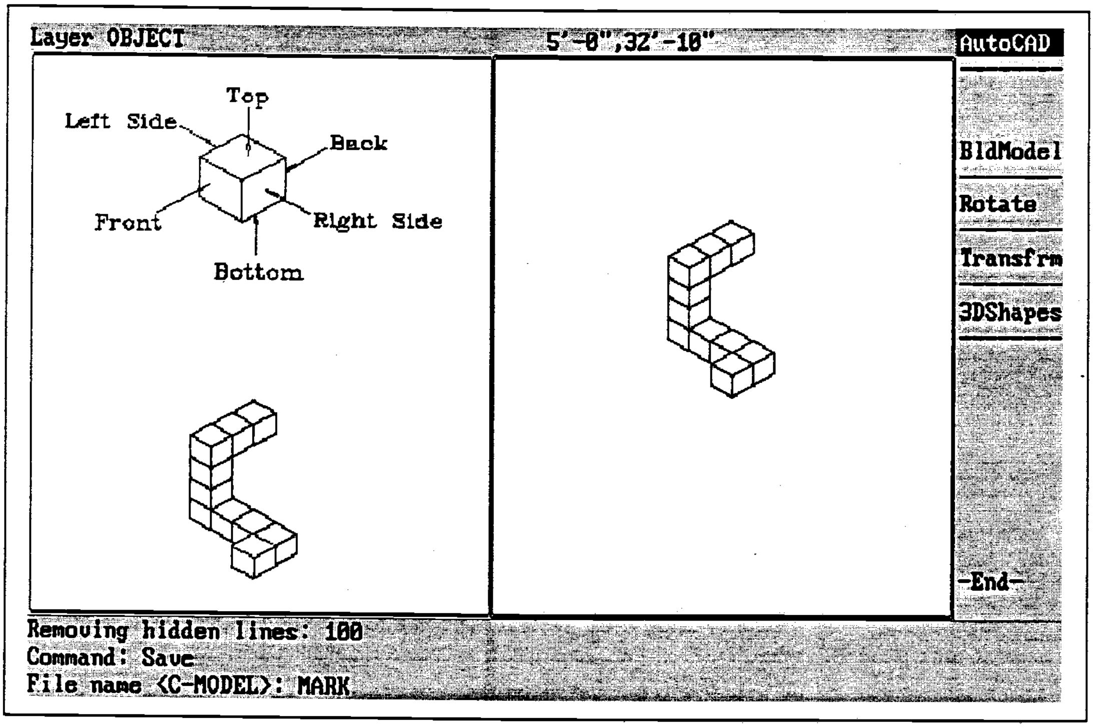
You finished the project. Good Job! Now select "End"

DO THIS



Now select "Save/End".

DO THIS



Now, enter your first name. It will show on the bottom of the screen.

DO THIS

```
          A U T O C A D
Copyright (C) 1982,83,84,85,86,87,88 Autodesk, Inc.
Release 10 (10/7/88) IBM PC
Advanced Drafting Extensions 3
Serial Number:  79-213129
NOT FOR RESALE
Current drawing:  C-MODEL

Main Menu

   0.  Exit AutoCAD
   1.  Begin a NEW drawing
   2.  Edit an EXISTING drawing
   3.  Plot a drawing
   4.  Printer Plot a drawing

   5.  Configure AutoCAD
   6.  File Utilities
   7.  Compile shape/font description file
   8.  Convert old drawing file

Enter selection:
```

When you see this screen, please tell your teacher. THANK YOU

DO THIS

This is the End of the Session.

APPENDIX B

Cyberspace Scripts

Cyberspace Script: Treatment 1

1. Place DataGlove on subjects right hand.

2. Calibrate computer to subjects hand gestures.

3. Place head-mounted display on subjects head.

   Read remaining instructions aloud.

4. I am going to help you turn so that you are facing the tracking device.
   (The subjects will not be able to see with head-set on, and will therefore require directional assistance)

5. Put you hand straight out in front of you with your palm down.

6. Now, make a fist.
   (System will signal in response to the fist gesture)

7. Open your hand.
   (External screen should display the cyberspace)

8. Do you see an office in front of you?

9. If yes continue.
   If no, check for loose wiring connections. If no loose wiring connections go through setup again.

10. Turn your head to the left. Did the picture change?

11. Look straight ahead again. Did the picture change again?

12. Turn your head to the right. Did the picture change again?

13. Look straight ahead again. Can you see the office in front of you again?
    If yes, continue.
    If no, turn your head until you can see the office in front of you.

14. Can you see the chair in the office?
    If yes, continue.
    If no, turn your head until you can see the chair.

15. Fly toward the chair.
    (Remember, that you fly toward the chair by pointing your index finger and squeezing the other three fingers of your glove hand)

16. Stop in front of the chair.
(Remember, open your hand to stop flying)

17. Now, let's grab the chair.

18. Make a fist with your glove hand and pass it through the chair.
If grasped, continue.
If not, move a couple of steps (forward or backward).

19. Raise your glove hand.

20. Do you have the chair in your hand?

21. Hold onto the chair. Now, turn and move your hand.

22. Does the chair move as you move your hand?
If yes, continue.
If no, go to 17.

23. Now, raise the chair above your head and toss the chair.
(Remember, to toss something, move your arm and hand just like you are going to throw a ball. Then just open your hand to release the chair)

24. Did you see the chair fly through the air?

25. Now, look straight up.

26. Let's fly up above the office. Point your finger straight up over your head and squeeze your other three fingers.
(Let subjects fly up for approximately 5 seconds. Travel is approximately 10 feet per second in this space)

27. Stop.
(If necessary, instruct subjects to open their hand to stop flying)

28. Now, look down and find the office. You may have to look around to find it.

29. Tell me when you see the office.

30. Fly back down to the office.
(If necessary, provide instructions)

31. Tell me when you are back in the office.

32. You may travel around the office for a couple of minutes. See what you can find.

33. After 2 minutes. Find the brown door.
    If found, continue.
    If not found, provide assistance in finding the door.

34. Now, fly through the door. This is a portal into a racquetball court.

35. Once you are inside, take a look around. Tell me what you see.
    (Inside the court there are two balls, a racquet and a teapot)

36. Fly to the objects and grasp one of the two balls.

37. Now, throw the ball toward one of the court walls.

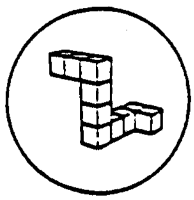
38. Did you see it flying through the air? Did it hit the wall?

39. That's all for now. I am going to remove the head-set. Now let's take off the glove.

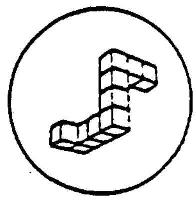
40. Thank you. You can go into the waiting room now.

<u>**Cyberspace Script: Treatment 2**</u>

Show the subject the following cube model drawings (i.e., descriptions).



Example
Cube Model



Mirror Image
of Example

<u>Read Aloud</u>

Look at the two drawings of the cube model. The model on the left is the example, and the model on the right is a mirror image of the example model. When you go into this cyberspace, these two models will be there. You are to find them, and then tell me which one matches the example model and which one matches the mirrored model. If you need to travel around the models before making your decision, you should do so. There are four other objects you are to try and find also. Each of these items are located close to the building. These items are: a ball, a book, a chair, and a racquet. Tell me when you find each of these items. You will have about fifteen minutes to complete this "treasure hunt." **Let's start the treasure hunt.**

1. Place DataGlove on subjects right hand.

2. Calibrate computer to subjects hand gestures.

3. Place head-mounted display on subjects head.

<u>**Read remaining instructions aloud.**</u>

4. I am going to help you turn so that you are facing the tracking device.
(The subjects will not be able to see with head-set on, and will therefore require directional assistance)

5. Put you hand straight out in front of you with your palm down.

6. Now, make a fist.
   (System will signal in response to the fist gesture)

7. Open your hand.
   (External screen should display the cyberspace)

8. Do you see a space with grass, mountains, blue sky, and a building made of four white posts and a box on top of them?

9. If yes continue.
   If no, check for loose wiring connections. If no loose wiring connections go through setup again.

10. Turn your head to the left. Did the picture change?

11. Look straight ahead again. Did the picture change again?

12. Turn your head to the right. Did the picture change again?

13. Look straight ahead again. Can you see the building in front of you again?
    If yes, continue.
    If no, turn your head until you can see the building in front of you.

14. Now, see if you can find the ball, the book, the chair, the racquet, and the cube models. Tell me when you find each of them.

    (Subjects will travel in this space to complete their designated tasks. Provide movement and manipulation instructions whenever necessary).

    <u>After 15 minutes</u>

14. That's all for now. I am going to remove the head-set. Now let's take off the glove.

15. Thank you. You can go into the waiting room now.