Making Connections: Improving Spatial Abilities with Engineering Drawing Activities

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Spatial thinking is essential for scientific thought; it is used to represent and manipulate information in learning and problem solving (Clements & Battista, 1992). It is also required in many intellectual endeavors such as solving problems in engineering, design, physics and mathematics (Smith, 1964; Pellegrino, Alderton & Shute, 1984). Enhancing students' spatial abilities is one of the roles of geometric activities. The National Council of Teachers of Mathematics recommends "the mathematics curriculum for grade 5-8 should include the study of the geometry of one, two, and three dimensions in a variety of situations, so that students can visualize and represent geometric figures with special attention to developing spatial sense" (NCTM, 1989). However, such is not the case. Current geometry curricula do not provide enough opportunities for the development of spatial ability (Usiskin, 1987). Moreover, in many schools geometry is delayed until the end of the school year (Hoffer & Hoffer, 1992) or eliminated (Porter, 1989).

The timing and the content are two crucial elements to be considered in designing instructional tasks to improve spatial ability. There is evidence (e.g., Salthouse, Babcock, Skovronek, Mitchel & Palmon, 1990) that spatial ability seems to reach a plateau at puberty and begins to decline in the late twenties due to the aging effect. Ben-Chaim, Lappan & Houang, (1988) suggest that seventh grade is an optimal time for the teaching of spatial visualization tasks. The kinds of activities that are said to improve spatial ability are very similar to what are being used in teaching engineering drawing (Baartmans & Sorby, 1996; Ben-Chaim, Lappan, Houang, 1985; Smail, 1983).

The purpose of this article is to provide activities for improving middle grade students' spatial ability with engineering drawing applications. To do this, first, spatial ability is described in the light of existing research. Then, engineering drawing is explained. Finally, activity examples for improving spatial ability are provided for school geometry classrooms in an engineering drawing context.

What is Spatial Ability?

In the literature, the concept of spatial ability is used for the abilities related to the use of space. Two major components of spatial ability have been identified: spatial relations and spatial visualization (McGee, 1979; Burnett & Lane, 1980; Elliot & Smith, 1983; Pellegrino *et al*., 1984; Clements & Battista, 1992).

In standardized spatial ability tests, *spatial relations* tasks involve 2D and 3D rotations and cube comparisons (see Appendix). Subjects are required to decide that one of the alternatives is the rotated version of the original stimulus. This factor seems to tap the ability to engage rapidly and accurately in mental transformation or rotation processes for judgements about the identity of a pair of stimuli (Pellegrino, *et al.*, 1984). Indeed, the stimulus is rotated as a whole body.

Spatial visualization is described as the ability to imagine rotations of objects or their parts in 3-D space (Burnet & Lane, 1980) by folding and unfolding, for example (McGee, 1979). The manipulation could be in a holistic, as well as piece-by-piece fashion (Battista, Wheatley & Talsma, 1989) and the movements must be imagined (Clement & Battista, 1992). The kinds of activities used to measure spatial visualization ability include form board, paper folding, and surface development (see Appendix). Such tasks frequently require a manipulation in which there is movement among the internal parts of a complex configuration and/or the folding and unfolding of flat patterns (Pellegrino, *et al.*, 1984). In a short definition, spatial visualization is the mental manipulation and integration of stimuli consisting of more than one part or movable parts.

As understood from the definitions, both factors involve some kind of mental manipulation of visual images. In just the same way, recent literature shows general agreement that spatial ability is the mental manipulation of objects (Kovac, 1989) and their parts in 2D and 3D space. Still, however, the differences between the tasks seem to represent two correlated dimensions of performance: speed-power and complexity (Pellegrino, *et al.*, 1984). In spatial relations tests subjects are required to complete the tasks in certain time, (i.e., speed is important) while visualization tests are relatively less speeded, (i.e., power is important). Spatial relations problems, although varying among themselves in complexity, involve less complex stimuli than spatial visualization tasks. As seen, the differences between the factors occur at the task level in terms of difficulty or complexity and the testing conditions such as timing. Therefore, it can be concluded that this separation of visual ability is artificial, and in fact, it is uni-faceted.

Table 1: Spatial Ability and its components

SPATIAL ABILITY		
Component	**Spatial Relations**	**Spatial Visualization**
Definition	Imagining the rotations of 2D and 3D objects as a whole body	Imagining the rotations of objects and their parts in 3D space in a holistic as well piece by piece fashion
Associated test	MGMP, Spatial Visualization Test, Primary Mental Abilities Test, French Reference Kit	MGMP, Spatial Visualization Test, Purdue Spatial Visualization Test, Minnesota Paper Form Board, Differential Aptitude Test, French Reference Kit
Typical test items	2D mental rotation, Cube comparison, 3D mental rotation.	Form board, Paper folding, Surface development, 2D-3D transformations
Complexity	Relatively simple tasks	Relatively complex tasks
Speed -power	Speed is important	Power is important

Although there is no agreement among the researchers as to what kind of activities constitute these two ability groups it is possible to make a list of activities that differentiate among the domains. Table 1 provides such a background.

How can Spatial Ability be improved?

Although there are somewhat conflicting results in the literature regarding whether spatial ability can be improved, numerous studies (e.g., Ben-Chaim *et al.*, 1988; Lord, 1985; Burnett & Lane, 1980) have indicated that it can be improved through training if appropriate materials are provided. As stated in the previous section, spatial relations tasks require one to imagine the rotations of 2D and 3D geometrical shapes, which can be found in many engineering drawing applications. Spatial visualization seems to tap the ability of mental integration, which is done while consolidating several orthographic views into a single image, perspective. Given the obvious connection between spatial thinking and transformational geometry, which is the base of engineering drawing, one might hypothesize that work with the latter would improve skills in the former (Clements & Battista, 1992).

The representations of a three-dimensional object by means of a two-dimensional diagram, either orthographic or perspective, demands considerable conventionalizing, which is by no means immediately recognizable (Bishop, 1979) especially by those who were not directly taught the conventions (Ben-Chaim *et al.*, 1985). Engineering drawing provides a context in which spatial ability can be improved through practicing these conventions.

Engineering Drawing

Engineering drawing is a means of graphical communication. It consists of some technical rules or drawing conventions and visual skills. Technical rules provide standardization. Baartmans & Sorby (1996) state "a standard drawing layout typically includes the top, front, and right-side views of the object (from the viewer's perspective, the right side is determined by looking at the front of the object), as well as an isometric or corner view of the object" (p. 348). Sectional views may also be needed to show the interior details of a complex object.

The top, front, right-side views, and sections are two-dimensional representations of a 3D object, each taken from an angle perpendicular to the referent side. The isometric view, on the other hand, is a two-dimensional drawing, taken from a certain angle so that a 3D object can be represented with its three dimensions on a plane surface. In general, those views that show only two dimensions of an object such as top, front, and right-side views, are called orthographic views, while the views that represent three dimensions are called perspective. Figure 1 shows a sample technical drawing.

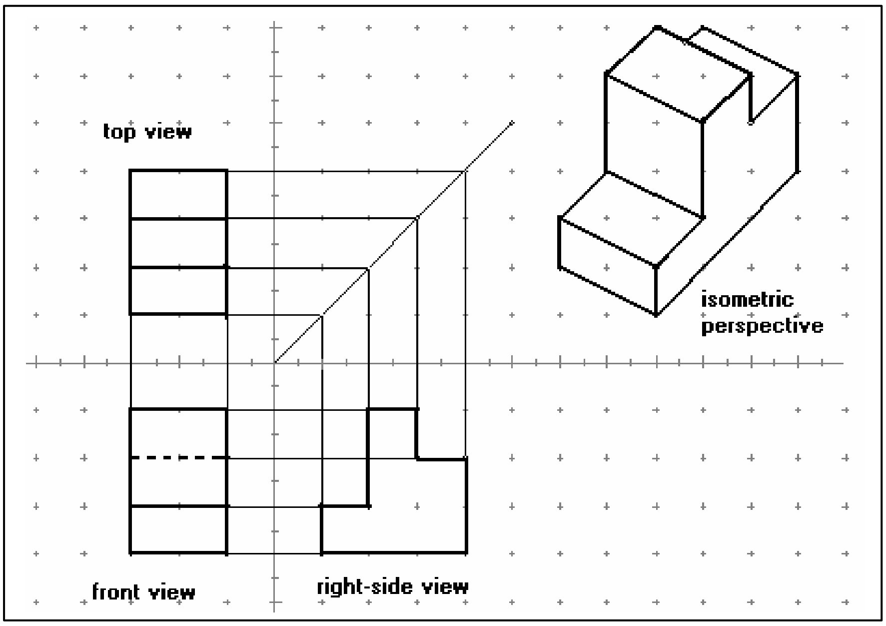


Figure 1. A sample technical drawing

As in other communication media, rules for making orthographic drawings are necessary for effective graphical communication (Baartmans & Sorby, 1996). Some of the basic rules are explained below (see Figure 1 as reference for each rule):

1. The orthographic views of an object should be aligned with one another. This rule gives a clue that the widths of the top view and of the front view are equal. Similarly, the heights in both the front and the side views are equal. These equalities are accomplished through alignment of the views. The equal lengths in the top and the side views are obtained through a 90-degrees rotation of the lengths.
2. When an orthographic drawing or sketch is created, lines are drawn to represent the edges of the object as line segments.
3. Hidden edges from the view are drawn as dashed lines, whereas visible edges are drawn as solid line segments, or object lines. In standard drawing practice, if an object line coincides with a hidden line, only the object line is shown.
4. The number of orthographic views is determined according to the real object. That is, orthographic views must be able to represent all of the dimensions of the real object so that the real object can be visualized from the orthographic views including section views. There are many other rules for technical drawing; however, these rules are enough for the purpose of this article.

Apart from the drawing rules summarized above, there are some skills involved in technical drawing. These skills are acquired through experiences with simple to more complex visual patterns. Understanding drawings means visualizing the geometrical form and the spatial layout of the object portrayed (Roorda, 1994). Since there are mainly two kinds of drawing, orthographic and perspective, it can occur in two different ways: Understanding the perspective and making its orthographic drawings, and the other way around, the integration of a number of different views into a single spatial image. The second task seems a little more difficult than the first one because the integration of a number of different views into a single spatial image depends on the correct reading of the views (Roorda, 1994), and therefore requires more neural attention (Lord, 1985).

Both drawings might have many geometrical figures such as circles, triangles, curves, lines etc. Therefore the spatial ability in technical drawing should supposedly involve, but is not limited to, the manipulation of different lines, curves, plane shapes, and solid figures, and the transformations between them. Drawing perspectives or imagining the real object from the orthographic views also involves mental integration.

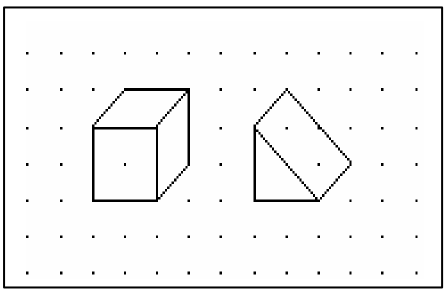
Some technical rules like alignment of the views, and line weights make the visualization easy to understand. Therefore, teaching higher order visualization skills for technical drawing should go hand in hand with technical rules. Shadowing and coloring also make the visualization easier. If the specific rules are taken out from the content, there remain visualization skills that are very similar to what are being used in spatial ability measurements. There is research evidence (e.g., Ben-Chaim *et al.*, 1988; Ben-Chaim *et al.*, 1985, Smail, 1983) that spatial skills might be enhanced by introductory lessons in technical drawing and three-dimensional work in wood and metal. In the next section, some activity examples are provided for geometry classrooms in order to make the students familiar with the conventions of technical drawing.

Activity Examples for Geometry Classrooms

Each task to improve spatial ability can be arranged in an incremental manner from simple to more complex. That is because there are some differences between spatial tasks in terms of cognitive complexity. Since subjects attempting to solve a problem involving a spatial phenomena form a mental picture of the event in their minds, simple images are most easily envisioned (Lord, 1985). Therefore, the best way to deal with each task is to present learners with first concrete and familiar examples. It is evidenced that after working with the concrete physical models, students progress to working without the models quite naturally (Baartmans & Sorby, 1996). In addition, freehand sketching enhances motor skills and shows actual imagining and doing. Some dot-paper or squared paper should be used as a drawing template as shown in figures below. That way the learning environment provides a context in which a variety of experiences can be gained.

Figure 2

Sample materials



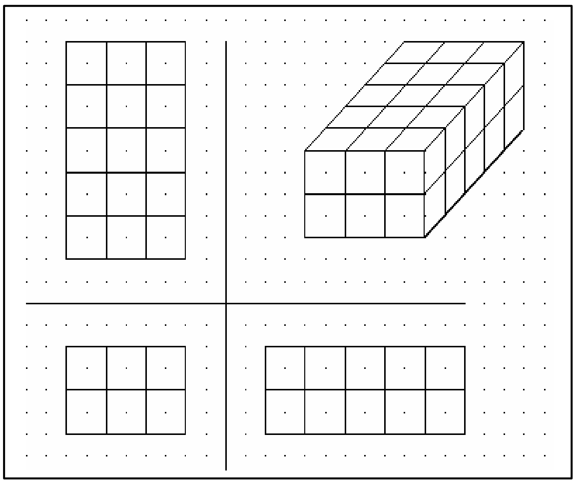
Necessary materials: For each student, prepare about fifty 2 by 2 by 2cm wooden cubes, five of them are diagonally cut into two pieces to form a triangular prism as shown in Figure 2. For drawing activities, prepare some squared paper, five to ten for each student.

Activity 1. Let's make a rectangular building

By using small cubes, have the students build the rectangular solid shown in Figure 3. Tell them this is a solid building with no space in it. Have them discuss and decide which view was taken from which side. This is the very basic step for middle grade students to build a rectangular solid and to associate its views to the perspective and the concrete object. Try to challenge them to build different rectangular solids.

Figure 3

Building a rectangular solid

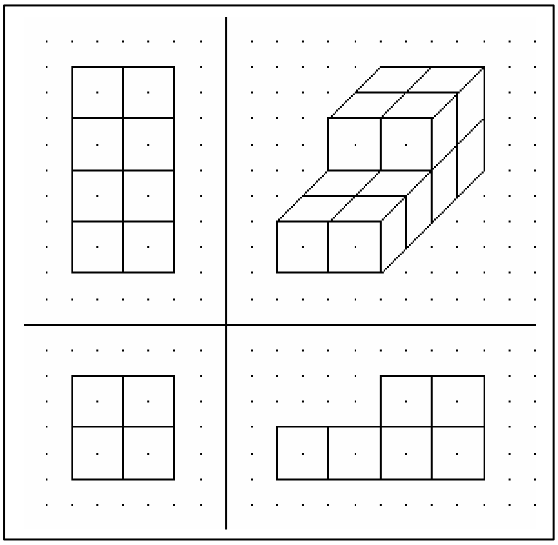


Activity 2. Let's try to make a car

Remove some of the parts from the building to make it look like a car, a very familiar object to many students. Then, take a look at the perspective and the corresponding views. Have the students discuss what changed and what remained the same. Destroy the car and have them rebuild it as in the Figure 4.

Figure 4

Make a car

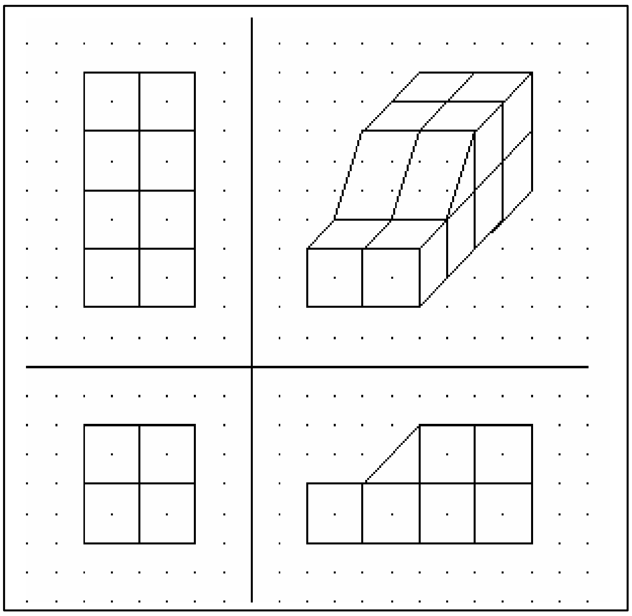


Activity 3. Let's try to make the car nicer

This time try to use triangular prisms to make the front window of the car (see Figure 5). Have the students direct their attention to the fact that an object can be seen differently from different angels. Encourage them to rebuild the car using its drawings.

Figure 5

Make a nice car



After examining concrete buildings and the drawings, students will see that a square face in the orthographic views look like a rhombus in the perspective drawing if it is on the oblique side. Similarly, a rectangular face looks like a parallelogram. An inclined surface in the perspective drawing will look like a little smaller in the orthographic views depending on its slope. In order for students to discover these geometrical transformations, have them find a specific part of the building first in the solid building, then in the perspective and in the orthographic views respectively.

More sophisticated examples: After having students become familiar enough with the conventions, challenge them to build some more sophisticated ones. Some examples are provided below (Figure 6 and 7).

Figure 6

Make a truck

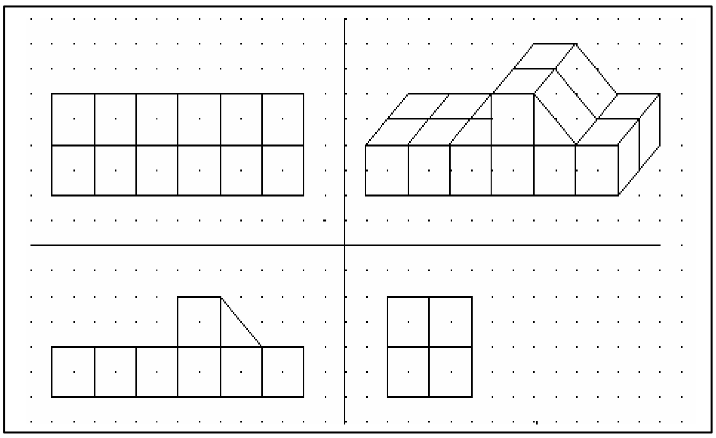
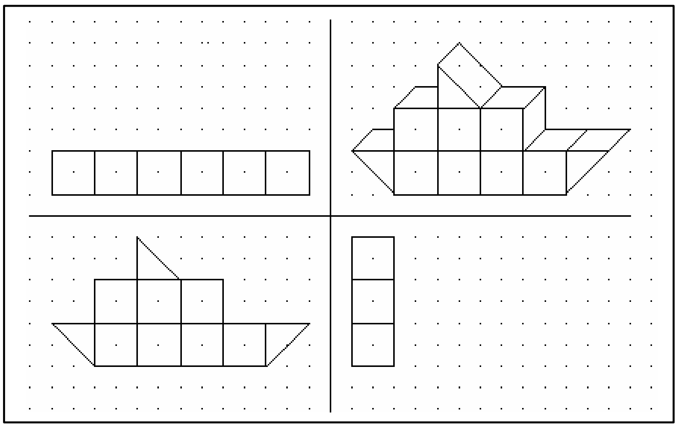


Figure 7

Make a ship



Then, you can start having them draw the views of their own buildings using squared papers. More and different activities for improving spatial ability can be found in Baartmans and Sorby (1996), Cruikshank and Shenfield (1992), and Young (1987).

Summary and Conclusion

Spatial ability is the mental manipulation of objects and their parts in 2D and 3D space. Research shows that spatial ability is important and can be improved through appropriate activities. Engineering drawing is chosen as a context for two important reasons: First, it has a practical base in real life situations. In many technical occupations, drawing conventions are required and taught. Basically, this skill involves representing objects in pictorial forms and visualizing objects from their drawings. Second, concrete experiences with geometrical objects and representing them in two-dimensional space are proved helpful in improving students' performance in spatial visualization.

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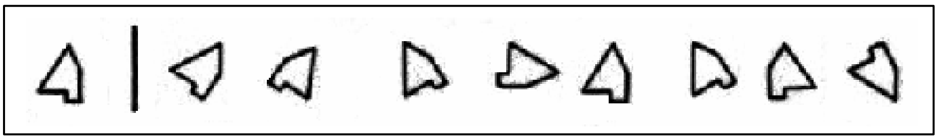
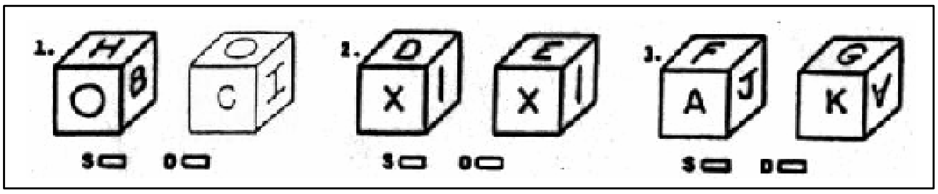
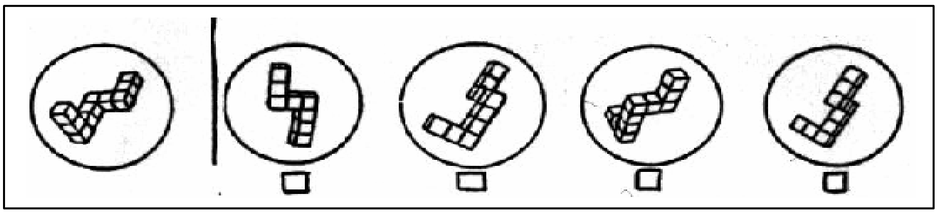
APPENDIX: Spatial Relations (SR) and Spatial Visualization (SV) tasks



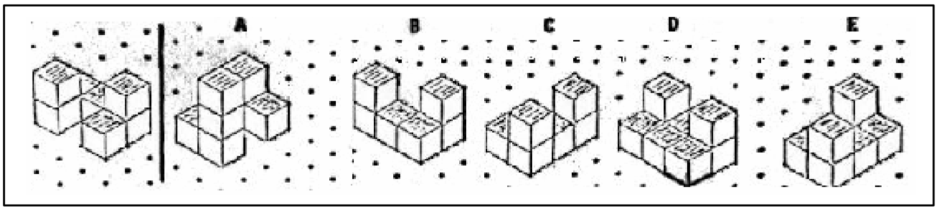
2D Mental rotation task (SR)



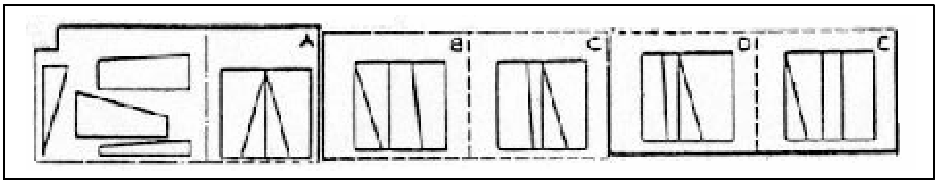
Cube Comparison (SR)



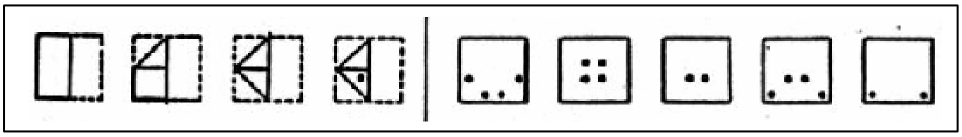
3D mental Rotation (SR)



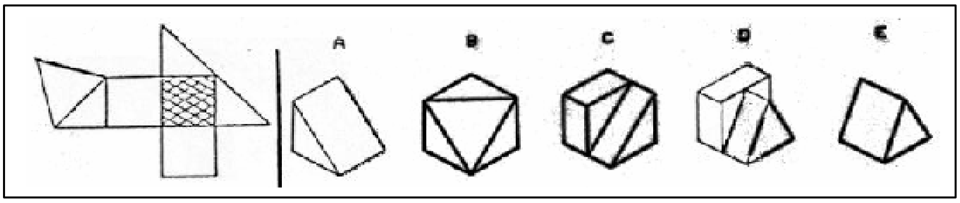
3D Mental Rotation (SR)



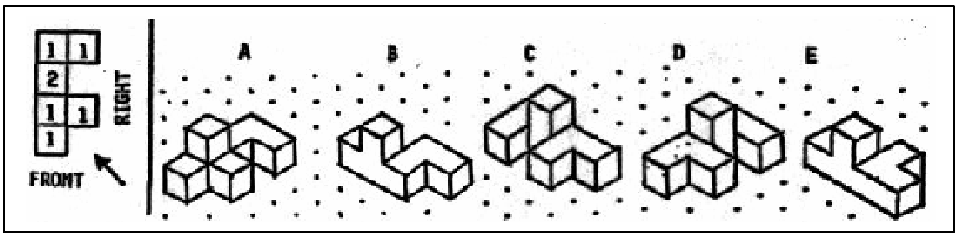
Form Board (SV)



Paper Folding (SV)



Surface Develop-ment (SV)



2D to 3D transfor-mation (SV)