Strategy Variability in Solving Spatial Visualization Tasks: Rethinking the Purdue Spatial Visualization Test - Developments

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STRATEGY VARIABILITY IN SOLVING SPATIAL VISUALIZATION TASKS: RETHINKING THE PURDUE SPATIAL VISUALIZATION TEST - DEVELOPMENTS

Abstract

The proposed research aims to understand the strategies involved in solving pattern development tasks from the Purdue Spatial Visualization Test (PSVT). Over the years in spatial ability, mental rotation and spatial orientation have been thoroughly examined to understand the mental processes involved in solving these types of problems. However, spatial visualization, which is captured by pattern development tasks has been minimally researched. The inherent processes in solving such tasks have not been extensively examined. The proposed research examines the strategies used by individuals in solving the Developments section of PSVT (PSVT-D). The idea was to investigate spatial visualization ability by eliminating the potential use of analytical skills in solving these problems. An endeavor was made to also examine the obstacles that prevent individuals from using either spatial or analytical strategies in solving pattern development tasks. It was hypothesized that test performance does not change significantly.

A population of 191 college students enrolled in a 100-level technical graphics course for civil engineering and construction were administered the PSVT. Based on their PSVT-D scores students were sampled into two groups of high and low spatial abilities. The students with high and low spatial ability were re-administered 5 questions from the PSVT-D. The students were asked to sketch an isometric view of the 3D object from the given 2D pattern. Using a think-aloud protocol the students were asked to explain their visualization process in order to elicit spatial thinking. After each sketch, the students were also asked to describe their visualization strategy used in solving the problem by using a cardboard cut-out to help specifically understand the obstacles of strategy use for those students who were not able to sketch the isometric object.

Introduction

Spatial ability research was nascent in 1883 when Galton projected his theory of imagery using the spatial sense. Later, Spearman in 1905 developed his two-factor theory of intelligence. He divided intelligence into general intelligence ‘G’ and several group specific factors ‘S’. Simon and Binet developed the first spatial ability test around the same time Spearman proposed his theory. It was known as the “Scales of Intelligence”.

Spatial ability research started gaining importance at the onset of World War I in 1918, when the United States Army conducted large scale testing procedures in order to enroll military personnel. These tests were called as Examination Alpha and Examination Beta. Examination Alpha was administered to literate personnel and consisted primarily of verbal material. Examination Beta was the battery of tests that included non-language tests, which were administered to the un-educated personnel. This was the first time that non-language and performance-based tests were administered on a large scale. Tests analogous to Examination Beta were later developed to test children for school enrollment and evaluate candidates for various occupations. This was one of the first instances of a spatial ability test being used for selection of candidates. Later, Alexander and Kohs provided evidence for the existence of a
spatial factor. But, the major breakthrough came when El Koussy proposed a group factor ‘K’ in the scores from spatial tests.

Over the years and predominantly between 1938 and 1961, researchers found spatial factors that differentiated from one another. Lohman categorized spatial ability into three primary spatial factors. The definitions for these factors differed from researcher to researcher and caused considerable confusion during that period. Visualization is “An ability to visualize a configuration in which there is movement or displacement among the internal parts of the configuration” (p. 518). Comprehending the arrangement of elements within a visual stimulus pattern and also the ability to remain unconfused by the changing orientation in which it is presented was spatial orientation. Carroll defined spatial relations as the speed in manipulating simple visual patterns by rotation, translation or transformation.

Spatial ability has a widespread application, wherein individuals have been known to use it in a variety of fields, including STEM education, music, sports, driving, and art. Spatial ability is a distinguishable component of intelligence that has been deeply studied and does not require an understanding of language. Very simply put, spatial ability can be termed as an inherent ability that individuals are born with, which can be refined over a period of time.

As spatial testing grew in importance, a number of spatial tests were developed over a period of time. These spatial tests focused on measuring an individual’s spatial ability over the primary spatial factors. The Vandenberg Mental Rotation test is an example of one such test that measures an individual’s mental rotation ability. Another test known as the Purdue Spatial Visualization test (PSVT) was created by Guay in 1977. The PSVT has been used for spatial testing over the past 40 years. It has primarily been used in educational settings to measure the spatial ability of students in various career fields. This test is important as it tests individual spatial abilities over the three primary spatial factors as mentioned earlier.

As early as 1950, the acknowledgement of two distinct types of strategies for solving spatial problems had been proposed by Spearman and Jones. Zimowski and Wothke identified them as non-analog (“verbal or general reasoning”) and analog problem solving strategies (“holistic, spatial”). It has also been acknowledged that many spatial measures contain non-analog components whilst the term “spatial” is still being referred to these tests that require the processing of visuospatial information. Analog strategies primarily include mental manipulation of the object’s orientation while understanding its spatial relation from the point of view of the test taker. Calculating faces and edges, looking for features to eliminate, comparing the relations between patterns come under the usage of non-analog strategies. Glück and Fitting summarized that a holistic strategy of visualizing the folding and unfolding of the figure and an analytic strategy of computing the folding result for each edge separately could be used for solving surface development problems, however no further experiment has been conducted to provide an in-depth explanation. It is worth noting that analytic (non-analog) and holistic (analog) strategies should be viewed as “poles of a continuum”, which means that people often utilize more than one strategy in solving spatial problems. And it’s also been found that the frequency of analytic strategies increases with increasing task difficulty. Most people can solve
simple tasks by using holistic strategies whereas complicated tasks could force people take a shortcut and use analytic strategies, which take longer time but less effort\textsuperscript{14}.

Mohler\textsuperscript{15} applied a phenomenological approach to examine how a student experiences the spatial ability phenomenon from a qualitative perspective. Within the same study, differences between how high and low spatial ability students experience spatial ability was also investigated. Mohler\textsuperscript{15} utilized the Vandenbeug Mental Rotations test to differentiate between high and low spatial ability students. Differences were observed between high and low spatial ability individuals, based on their strategies for visualization. The low spatial ability individuals also had difficulty in visualizing multi-view representations of objects. The high spatial ability individuals employed a strategy to break down the whole object into individual parts before reconstructing it. The low spatial ability individuals also complained that they were unable to visualize the views altogether.

The use of strategy in various spatial tests, including Guilford-Zimmerman Spatial Visualization Test, Wiggly Block Test, Paper Folding Test, DAT-SR, Block Counting task, Vandenbeng and Kuse Test of Three-Dimensional Spatial Visualization, Road Map Test of Direction Sense, Nebes’s Circle Matching Test, cube-comparison task, and “map test” involving way-finding, has been extensively explored\textsuperscript{13,16,17,18}. Based on Spatial Strategy Questionnaire, Schultz\textsuperscript{18} has identified three solution strategies for spatial problems: a mental rotation strategy, a perspective change strategy, and an analytic strategy. However, the strategy use in PSVT has not been investigated. Cochran and Wheatley\textsuperscript{17} investigated the Visualization of Rotations subset of PSVT quantitatively in order to argue that the spatial ability tests differ in the number and type of strategies that can be used to solve the test problem. Beyond that there was little research to analyze the specific holistic strategies used in solving a spatial test, especially for the Developments section of PSVT.

**Methodology**

This study is primarily a qualitative research study that aims to identify the strategy used by high and low spatial ability individuals in solving pattern development tasks from the Developments section of the Purdue Spatial Visualization test. A qualitative methodology was ideal for this study because it helps in understanding how an individual visualizes while observing a spatial problem. Moreover, quantitative methods fail to capture the same information.

The participants for the study were sampled from a 100-level Construction Graphics course at a university. Before sampling the participants for this study, 191 students from the course were administered the 30-minute version of the PSVT, which contained all three sections. Based on their performance, the individuals who scored the maximum and minimum on the test were selected for this study. Initially, the researchers had decided to select 10 high spatial ability individuals, and 5 low spatial ability individuals. However, due to unavailability of participants, 7 high spatial ability individuals and 1 low spatial ability individual participated in the study.

The instrument used for testing was the Purdue Spatial Visualization Test. There are three sub sections in the PSVT, namely visualization of developments, mental rotations and visualization of views. Five out of the 12 test questions were selected from the visualization of development
subset. As shown in Fig. 1, the selected questions were re-arranged in the order of increasing difficulty. The last question involved a cylindrical object. Isometric paper was provided to the participants for sketching. The testing was conducted in a room blocking out noise and other disturbances. Each participant was administered the study individually.

![Figure 1](image1.png)

Problem 1  Problem 2

Problem 3  Problem 4  Problem 5

Figure-1 Problem set extracted from PSVT-Developments

The selected participants were tested individually and each session lasted for 30-60 min. During the testing session, each participant was asked to sketch the corresponding three-dimensional (3D) isometric view from the given two-dimensional (2D) pattern. As they were sketching the isometric view, they were asked to describe their deliberation and visualization process verbally. After the completion of each question, a cardboard cut-out in the shape of the 2D pattern was given to the participant.

![Figure 2](image2.png)

Figure-2(a) Participant solving a problem by sketching
The data collected included the final isometric sketch, the transcripts generated from the recorded audio/video while sketching and manipulating cardboard, and the interview. These data were analyzed to understand patterns in problem solving adopted by the participants. Moreover, the primary goal was to understand the differences in the visualization process employed by each individual.

**Results**

After testing eight participants in the study, three essential strategies were observed based on different strategies employed by the participants. These patterns were extracted after analyzing the participant’s solutions, answers to the interview questions and the recorded explanations as they were solving each problem. The transcribed data was analyzed for evident patterns used by the participants in the study. Each participant’s transcript was thoroughly looked into for obvious solution strategies. Based on the different strategies employed, groups for each strategy were created. These groups helped to discern and identify specific solution strategies.

As mentioned earlier, each participant attempted 5 questions from the Development section of the PSVT. It must however be noted that strategies did change based on the question being attempted by the participants, however, it did not change drastically unless their chosen strategy was unsuccessful.

The three primary patterns extracted from the data have been described below.

**Starting from the base face and moving to the sides**

The most common strategy adopted by the participants was identification of the base, by fixing its position, before folding the sides of the pattern in order to complete the 3D object. This strategy was used by four of the eight participants in the study. The idea behind fixating the base was to understand how the remaining vertical sides of the pattern wrap around the base to create
the 3D object. Moreover, it must be noted that the four participants that adopted this strategy were all from the high spatial ability group.

Typically, the participants identified each side connected to the base as references for the smaller faces. It was interesting to note, how the visualization process was a sequence, wherein the individual completed the folding of one side, before moving on to the other side of the base.

Identification of the biggest face
The second most commonly used strategy was to identify the biggest face in the 2D pattern and use this face as reference to visualize the folding up of the other faces. The biggest face acted as a link between the base and the other smaller faces. A participant mentioned folding the bigger face, helped in understanding how the other small faces would fold along with the bigger face and just fall into place. This strategy was used along with the previous strategy on multiple occasions by a couple of participants.

Starting from the side faces
The third strategy observed during the testing session emphasized the usage of connected faces that had a common edge with the base on either side. This strategy was typically straightforward in the sense that the participants using it focused on one side at a time, and eventually folded the top faces to complete the object. The participants using this strategy focused on the edges rather than the faces themselves. As they explained the visualization process, the edges were used as defining elements in folding the object. Moreover, the only individual using this strategy was from the low spatial ability group.

Analytic strategies
The use of analytic strategies was observed although the investigators endeavored to eliminate the possibility that the participants could’ve applied such strategies for solving the problem. For example, after starting with the base, Participant 2 measured the length of the edges before matching the edges with the same length in order to fold up the shape. It was interesting to observe how this particular participant, who was from the high spatial ability group, was able to visualize the entire objects for Problem 1, 2, and 5. The investigators inferred that this participant probably utilized analytic strategies as a shortcut to complete the visualization process by taking less effort.

Participants’ demographic information along with their answers to the interview questions is shown in Table-1. Four participants out of the eight, who are all from the high spatial ability group, had prior experience in engineering design, technical drawing, or computer-aided design before taking the 100-level construction graphics course. Six of the participants are currently majoring in civil engineering (CE) or construction engineering management (CEM). Seven of the eight participants reported that isometric sketching helped them visualize better. The other participant reported that visualization assisted with his sketching. All participants reported the physical card-board cut-outs were more beneficial in helping them visualize compared to the sketching. Only one participant reported that he could visualize the entire object before beginning the sketch on some of the problems.
**Discussion**

The analysis of the data provided three key patterns used by the participants in visualizing the transformation of (2D) pattern into (3D) isometric view. Each of these patterns were not specific to an individual or a group. In some cases, participants used more than one strategy in solving the questions. As there was only one low spatial ability participant in the study, identifying differences in the strategy adopted by high and low spatial ability participants would be unfair. However, the approach employed by the participants would be intriguing to discuss.

<table>
<thead>
<tr>
<th>Participant 1</th>
<th>Basic Strategy</th>
<th>Does sketching help you visualize?</th>
<th>Was the physical object better than sketching it on iso paper?</th>
<th>Do you have the entire object in mind before you start sketching?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male, FYE</td>
<td>Fixated the base. Iso view and then folded sides (vertical faces) and then top.</td>
<td>No. Visualization helped me draw better.</td>
<td>Yes, they did. Knew what they looked like. Made him confident.</td>
<td>No, I didn’t. Went step by step and then realized what final object was.</td>
</tr>
<tr>
<td>(Prior Experience)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 2</td>
<td>Started with the base and what can be seen in the visualization by measuring the unit.</td>
<td>Yes, it does.</td>
<td>Yes.</td>
<td>Yes, I saw the entire object in my mind for 3 objects. For others I knew certain parts.</td>
</tr>
<tr>
<td>Male, FYE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prior Experience)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Participant 3</td>
<td>Started with the base. Folded one side and connected faces. Then the other side. Then the back.</td>
<td>Yes, it does.</td>
<td>Yes.</td>
<td>No, I was having it as I sketched it.</td>
</tr>
<tr>
<td>Female, Civil Eng.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prior Experience)</td>
<td></td>
<td></td>
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<tr>
<td>Participant 4</td>
<td>Started at the sides. One side, then the other and finally the smaller ones attached to the big faces.</td>
<td>Yes, it does. Had better idea after every drawn face and edge.</td>
<td>Yes.</td>
<td>No, it was step by step.</td>
</tr>
<tr>
<td>(Low Spatial)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male, Civil Eng.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participant 5</td>
<td>Started with the bottom face, then the sides attached to the bottom.</td>
<td>Yes, sketching did help in visualization.</td>
<td>Yes.</td>
<td>No, it was one by one.</td>
</tr>
<tr>
<td>Male, Civil Eng.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Participant 6</td>
<td>Started with the base.</td>
<td>Yes. It helps keep on track in the mind and it saves more mind space into work.</td>
<td>Yes. It makes me more confident with the answers.</td>
<td>No, step by step.</td>
</tr>
<tr>
<td>Male, CEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Prior Experience)</td>
<td></td>
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</tbody>
</table>
Participant 7
Female, CEM

Started with back face and then the connected sides. Then base. And then remaining faces.

Yes, it does help me visualize better.

Yes.

No, I went step by step.

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Participant 8
Male, Civil Eng.

Started with the bottom face, then the side faces connected to bottom. Then the remaining.

Yes, it was helpful.

Yes.

No, I went step-by-step

<table>
<thead>
<tr>
<th>Participant demographics and after-test interview table by participant</th>
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<tbody>
<tr>
<td><strong>Participant 7</strong></td>
</tr>
<tr>
<td><strong>Female, CEM</strong></td>
</tr>
<tr>
<td>Started with back face and then the connected sides. Then base. And then remaining faces.</td>
</tr>
<tr>
<td>Yes, it does help me visualize better.</td>
</tr>
<tr>
<td>Yes.</td>
</tr>
<tr>
<td>No, I went step by step.</td>
</tr>
</tbody>
</table>

Beginning from the base face was a frequently used strategy by most of the participants in this study. Each PSVT-Developments question, identifies a base feature as the reference point for individuals attempting the test (denoted by shading in Fig.1). The participants used this as a reference point through which the rest of the object was constructed. Participants using this strategy, fixated the base on the horizontal plane, before rotating it in an isometric orientation. Once the base was fixed, the orientation became clear, helping the participants fold the faces according to their convenience. The idea behind starting at the base emanates from sketching an object in isometric view, and it is worth questioning whether sketching strategies are the primary reason for using this strategy.

Using the bigger faces as the reference shows a more direct strategy in visualization. The reason being, all the smaller faces are connected to these big faces. As the big faces are folded, the smaller faces follow suit in order to complete the (3D) isometric view. Although this strategy was used on multiple occasions by the participants, it was typically used along with other strategies.

A few participants also mentioned breaking down the bigger faces into small parts that can be easily visualized, to help keep track of how faces line up. They also mentioned it was easier to work with squares, rather than triangles as faces. This is what a participant stated,

“But you pick a smaller piece like A, it’s harder to draw a bigger piece off of it and imagine how things should fit with it. And plus it’s also a triangle, I like starting with something that is a square. Something’s that got like a… it’s easier to split this into for example.”

The third strategy focused on folding the sides connected to the base face, after which the participant ended up completing one side at a time, before folding down the top faces. It should be noted that the participant employing this strategy was sampled into the low spatial ability group. This piece of information is imperative because the visualization skills of the participant were limited. However, the participant performed as well as the participants from the high spatial ability group. This begs a question whether sketching and visualization are related in anyway. It seems plausible that sketching and visualization are completely unrelated, however, there appears to be some visualization skills that are necessary to help solve the questions in the test. The fact that the participant used edges as references to create the (3D) isometric view explains
how sketching assisted his minimal visualization skills and helped him complete the required
task without much difficulty. It must however be noted that this participant did spend more time
on an average compared to the other participants to complete the tasks.

The participants ended up using the same strategy for both the isometric sketch and the physical
cardboard cut-out. The physical object was used by the participants to reinforce the idea that
their sketches were correct. This was observed in all the participants as they manipulated the
cardboard cut-out of the (2D) pattern. Also, a very interesting trend was observed with respect to
some of the participants from the high spatial ability group. On the rare occasions that the
participants got stuck while sketching, an alternative visualization strategy was quickly devised
to solve the problem. The ability to switch between strategies and identify the faults with your
current strategy are highlights of individuals with high spatial ability.

**Conclusions**

This study employed a qualitative method to examine the use of holistic strategies in solving
spatial problems from the visualization of developments section in Purdue Spatial Visualization
Test. Following the think-aloud protocol the study analyzed the thinking processes of high and
low spatial ability participants for visualizing 2D pattern to 3D object by sketching and folding
up the cardboard model. The study subtly quarantined the influence brought by the original
multiple choices, namely the use of analytic strategies, in order to discern three types of holistic
problem solving strategy patterns.

Although this study could not clearly define differences between strategies used by high and low
spatial ability individuals, the results of the study provide interesting information on the ease
with which high spatial ability individuals solved the problem. A lot has to do with the fact that
sketching helped the individuals visualize as they did not have to maintain the images in their
mind for an extended period of time. However, it should be noted that visualization can work
both ways, wherein it can be enhanced by sketching and also be used as tool to enhance
sketching.

The fact that high spatial ability individuals can switch between strategies with ease helps in
understanding the flexibility of their visualization ability. The same cannot be said about the low
spatial ability individuals, as their strategies are usually one-dimensional.

Future plan would be to focus on recruiting more participants from both high and low spatial
ability group to consolidate the findings in this paper as well as to explore the potential
drawbacks in the PSVT. It would also be interesting to investigate the process of visualization by
eliminating sketching as a means to elicit information, as there is an indication that sketching
helps in visualizing the object better.

**References**