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Cognitive Skills and Mathematics Problem-Solving Performance

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COGNITIVE SKILLS AND MATHEMATICS PROBLEM-SOLVING PERFORMANCE

Ardyth C. Foster, PhD
Armstrong State University
GERA Conference Presentation (Fall, 2014)
The Problem

- Importance of problem solving as a means to mathematics learning
- Mathematics learned through problem solving; mathematical ideas develop along with problem-solving capabilities
Interactions between Cognitive Skills and Problem-Solving Performance

- Spatial skills and production and use of drawings to solve word problems
- Verbal skills & mathematical problem-solving performance; associated with higher cognitive functions (critical thinking, sound reasoning, problem solving)
- Logical/Analytical component also related to problem solving
- Logical/Analytical skills tightly linked to verbal skills
Definition of Terms

► Problem Solving – activities that range from word problems to open-ended, exploratory types of problems, covering a variety of mathematical content; Polya’s (1945) idea of steps used by students during the problem-solving process

► Spatial Skills – spatial visualization, spatial orientation, and visual imagery
Definition of Terms (cont’d.)

- **Verbal Skills** – *students’ understanding of vocabulary*

- **Analytical Skills** – *students’ ability to draw conclusions in syllogistic format*
Significance of the Study

- Previous research not organized around a common framework
- Lack of consensus in researchers’ definitions of problem solving
- Definition and interpretation of verbal, spatial & analytical skills
- Difficulties analyzing & measuring spatial-orientation and spatial-visualization tasks separately
Significance of the Study (cont’d.)

► Inconclusive findings

► More systematic examination of relationships among each of the cognitive skills and problem-solving performance

► More precise assessment of verbal and analytical skills – measured using separate instruments
The Research Question

To what extent are students’ spatial, verbal, and analytical skills related to their problem-solving performance?

- To what extent are students’ spatial, verbal, and analytical skills related to problem-solving performance on items that require verbal responses (e.g., explanation of a solution)?

- To what extent are students’ spatial, verbal, and analytical skills related to problem-solving performance on items for which a drawing or diagram is required for the main solution to the problem?
The Research Question
(cont’d.)

To what extent are students’ spatial, verbal, and analytical skills related to each other?

- To what extent are students’ verbal and analytical skills related to each other?
- To what extent are students’ spatial and analytical skills related to each other?
- To what extent are students’ spatial and verbal skills related to each other?
Method

Research Design

► Correlational study

► Relationships between each of the cognitive skills and verbal-response items, spatial-response items, and overall problem-solving performance

► Pair-wise relationships among the cognitive skills
Subjects

► Ninety-eight (98) students

- Private, Montessori-based school – 48 students;
  - 5th grade (11); 6th grade (10); 7th grade (15); 8th grade (12)
- Public charter school – 50 students;
  - 7th grade (25); 8th grade (25)
Instruments

Problem-Solving Test - two subtests

- PST-Spatial (20 spatial-response items)
  - Create a drawing/diagram represents relevant aspects of problem
  - Use the created drawing/diagram to solve problem

- PST-Verbal (20 verbal-response items)
  - Solve problem; describe solution to a friend
  - Give written step-by-step description of solution process
Cognitive Tests

- Spatial skills – Factor Referenced Cognitive Test of Visualization (ETS, 1976)
- Measures of ability to manipulate or transform images of spatial patterns into other arrangements
  - Part 1 (Form Board Test) – figure completion
  - Part 2 (Paper Folding Test) – hole punches
Instruments (cont’d.)

- Verbal skills – Factor Referenced Cognitive Test of Verbal Comprehension – Vocabulary Test (ETS, 1976)
- Measure students’ ability to understand the English language
  - Vocabulary I
  - Vocabulary II
**Instruments (cont’d.)**

- **Analytical skills** – Factor Referenced Cognitive Test of Logical Reasoning (ETS, 1976)
- **Measure students’ ability to determine whether or not a conclusion is logically correct**
  - Part I – Nonsense Syllogisms
  - Part III – Inference Test
Data Collection Procedure

► Data collected in two phases

- Phase 1 – Problem-solving instrument
  - Two problems (one spatial-response; one verbal-response)/day over four weeks
  - Administered in order of increasing difficulty
  - Used as bell-ringer/warm-up

- Phase 2 – Cognitive skills assessments
  - One assessment per day (i.e., spatial, verbal, and analytical skills) over three days
  - 15-20 minutes/assessment
Data Analysis

► Source of Scoring Guides/Obtaining Test Scores
  ▪ Problem-solving test
    ► Task-specific rubrics & rules for applying the rubrics
    ► Score of 1 (correct response) or 0 (incorrect response)
    ► Dichotomous scoring for reliability measures (Hopkins, Stanley, & Hopkins; 1990)
    ► Maximum PST-Spatial score of 20; PST-Verbal score of 20; PST-Overall score of 40
    ► Converted to percentage scores
Data Analysis (cont’d.)

- **Cognitive skills assessments**
  - Based on scoring guides provided by test developers
  - Responses scored “right” or “wrong”
  - Scoring methods varied by test segments (e.g.: correct responses – incorrect responses; correct responses – 25% of incorrect responses)
  - Students therefore had possibility of obtaining negative scores
  - Maximum spatial score of 68; verbal score of 54; analytical score of 50
► Frequency Analysis
  - Measures of central tendency
  - Range & distribution of scores

► Multiple Regression Analysis
  - Independent variables: spatial skills, verbal skills, analytical skills
  - Dependent variables: PST-Spatial scores, PST-Verbal scores, PST-Overall scores
  - Significance established at $p \leq 0.05$

► Correlation Analysis
  - Determine pair-wise relationships among the cognitive skills
  - *a priori* decision: correlation of .70 or greater - a very strong relationship between variables
# Results

## Frequency Analysis: Problem-Solving Performance

<table>
<thead>
<tr>
<th></th>
<th>Distribution &amp; Range</th>
<th>Mean &amp; Standard Deviation</th>
<th>Percentage of Students at or above Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PST-Verbal Subtest Scores</strong></td>
<td>Normal Distribution 5% - 95%</td>
<td>( m = 39%^* ) ( s.d. = 20.67 )</td>
<td>45%</td>
</tr>
<tr>
<td><strong>PST-Spatial Subtest Scores</strong></td>
<td>Normal Distribution 0% - 75%</td>
<td>( m = 38%^* ) ( s.d. = 18.48 )</td>
<td>54%</td>
</tr>
<tr>
<td><strong>PST-Overall Scores</strong></td>
<td>Normal Distribution 5% - 84%</td>
<td>( m = 39% ) ( s.d. = 17.89 )</td>
<td>51%</td>
</tr>
</tbody>
</table>
Frequency Analysis: Problem-Solving Performance (cont’d.)

- Difference between PST-Verbal & PST-Spatial means statistically significant \[ t(68) = 15.608; p = .000 \]

- Students performed better on PST-Verbal than on PST-Spatial subtests
  - 46.4% - higher PST-Verbal than PST-Spatial scores
  - 40.6% - higher PST-Spatial than PST-Verbal scores
  - 13% - equivalent PST-Verbal and PST-Spatial scores
## Frequency Analysis: Cognitive Test Performance

<table>
<thead>
<tr>
<th></th>
<th>Distribution &amp; Range</th>
<th>Mean &amp; Standard Deviation</th>
<th>Percentage of Students at or above Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Verbal Skills Scores</strong></td>
<td>Normal Distribution -3 to 44.5</td>
<td>$m = 17.98$</td>
<td>49%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$s.d. = 11.3$</td>
<td></td>
</tr>
<tr>
<td><strong>Spatial Skills Scores</strong></td>
<td>Normal Distribution -54 to 32</td>
<td>$m = -4.93$</td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$s.d. = 20.8$</td>
<td></td>
</tr>
<tr>
<td><strong>Analytical Skills Scores</strong></td>
<td>Normal Distribution -11 to 33.25</td>
<td>$m = 6.59$</td>
<td>43%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$s.d. = 8.34$</td>
<td></td>
</tr>
</tbody>
</table>
Frequency Analysis: Cognitive Test Performance (cont’d.)

- Students tended to have higher verbal than spatial skills - 89.9% scored higher on verbal than spatial skills assessments

- Only 51% of those had higher PST-Verbal than PST-Spatial scores
Results: Regression Analysis

- Results of Regression Analysis
  - PST-Verbal Subtest scores
    - Relationships with spatial and analytical skills stronger than relationship with verbal skills
  - PST-Spatial Subtest scores
    - Relationship with verbal skills stronger than relationship with spatial or analytical skills
  - PST-Overall scores
    - Relationships with verbal and spatial skills stronger than relationship with analytical skills
Results: Correlation Analysis

► Results of Correlations

- Cognitive Skills & PST-Verbal Performance
  ► Strongest relationship with spatial skills (.528)
  ► Similar relationships with verbal and analytical skills (.486 and .484, respectively)

- Cognitive Skills & PST-Spatial Performance
  ► Strongest relationship with verbal skills (.672)
  ► Weaker relationships with spatial and analytical skills (.591 and .487, respectively)
Correlation Analysis (cont’d.)

- Cognitive Skills and PST-Overall Performance
  - Relatively similar relationships with verbal and spatial skills (.625 and .607, respectively)
  - Weakest relationship with analytical skills (.531)

- Relationships among the Cognitive Skills
  - Significant, but not very strong pair-wise relationships (below .70)
  - Verbal and spatial (.551); verbal and analytical (.636); spatial and analytical (.470)
Findings

Relationships between students’ verbal skills and performance on PST-Verbal problems

- Not clearly defined – not as strong as would be expected
- **Stronger relationship with spatial skills**
- Stronger verbal than spatial skills not necessarily related to higher PST-Verbal scores
- Similar relationship with analytical skills

Relationships between spatial skills and performance on PST-Spatial problems

- Not clearly defined – not as strong as would be expected
- **Stronger relationship with verbal skills**
- Higher PST-Spatial scores not necessarily achieved by students with stronger spatial than verbal skills
Findings (cont’d.)

- Students with equivalent PST-Verbal and PST-Spatial scores did not have similar verbal and spatial skills scores (i.e., within 5 points)
Limitations of Findings

► Spatial skills assessment instrument: Does it assess different skills than those required for producing/using a drawing to solve math problem?

► Sample size
## Discussion: Relationships between Cognitive Skills and PST-Verbal Performance

<table>
<thead>
<tr>
<th>Findings</th>
<th>Prior Research Supported</th>
<th>Prior Research Not Supported</th>
<th>Not Addressed by Prior Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal skills not necessarily related to performance on verbal-response items</td>
<td></td>
<td><strong>Lean &amp; Clements (1981)</strong> – Students using verbal-logical means outperform others</td>
<td></td>
</tr>
<tr>
<td>Stronger relationship with spatial skills</td>
<td></td>
<td></td>
<td><strong>No such relationship indicated by previous research</strong></td>
</tr>
<tr>
<td>Relationship with analytical skills similar to relationship with verbal skills</td>
<td><strong>Battista (1990)</strong> – verbal syllogisms &amp; mathematics performance; <strong>Lean &amp; Clements (1981)</strong> – visual vs. verbal-logical</td>
<td><strong>Lean &amp; Clements (1981)</strong> – Strict dichotomy not supported</td>
<td></td>
</tr>
</tbody>
</table>
# Relationships between Cognitive Skills and PST-Spatial Performance

<table>
<thead>
<tr>
<th>Findings</th>
<th>Prior Research Supported</th>
<th>Prior Research Not Supported</th>
</tr>
</thead>
</table>
| Spatial skills not necessarily related to performance on spatial-response items | **Fennema & Tartre** (1985) – no difference in accuracy of mathematical solutions between students with high/low spatial or verbal abilities;  
  **Landau** (1984) – pictorial representations not helpful;  
  **Presmeg** (1986a) – standard vs. nonstandard diagrams; produce inflexible thinking & inability to recognize concepts | **Battista** (1990) – spatial visualization & logical reasoning significantly related to geometrical problem solving |
| Weak relationship with analytical skills                                  | **Eisenberg & Dreyfus** (1986) – visual or analytical approaches used by “expert” mathematicians;  
  **Lean & Clements** (1981) – verbal-logical vs. visual approach                                                                 |                                                                                              |
### Relationships between Cognitive Skills and PST-Overall Performance

<table>
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<th>Findings</th>
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<th>Prior Research Not Supported</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verbal &amp; spatial skills have relatively strong, relatively equal relationships to overall problem-solving performance</td>
<td><strong>Fennema &amp; Tartre</strong> (1985) – high spatial/low verbal, or high verbal/low spatial and accurate mathematical solutions; <strong>Landau</strong> (1984) – strong relationship with spatial skills</td>
<td><strong>Lean &amp; Clements</strong> (1981) – spatial conventions have small influence; <strong>Fennema &amp; Tartre</strong> (1985) – emphasis on spatial skills not effective</td>
</tr>
<tr>
<td>Practically significant relationship with analytical skills</td>
<td><strong>Krutetskii</strong> (1976) – logical/analytical component &amp; overall problem-solving performance</td>
<td></td>
</tr>
</tbody>
</table>
## Pair-Wise Relationships among Spatial, Visual, and Analytical Skills

<table>
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<th>Not Addressed by Prior Research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Verbal &amp; analytical skills:</strong> statistically significant relationship</td>
<td>Battista (1990)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lean &amp; Clements (1981)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatial &amp; analytical skills:</strong> Statistically significant relationship</td>
<td>Battista (1990); Lean &amp; Clements (1981) – viewed as existing at opposite ends of a scale</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spatial &amp; verbal skills:</strong> Statistically significant relationship</td>
<td>Fennema &amp; Tartre (1985) – viewed as discrepant</td>
<td></td>
<td>Any relationship between the two ignored in the literature</td>
</tr>
</tbody>
</table>
Implications

► Cognitive skill strength vs. mathematical conceptual knowledge
  ▪ Future Research: Investigate & unravel complexities
  ▪ **Teaching Practice:** Interpret student performance with respect to math understanding and skill strength

► Effective use of cognitive skills for expression of mathematical ideas may be a learned skill
  ▪ Future Research: Will teaching students effective strategies influence problem-solving performance?
  ▪ **Teaching Practice:** Instruction on strategies for effective use of skills; practice on both skill types
  ▪ **Teacher Education:** Pre-service training & examples of effective instructional strategies
Implications (cont’d.)

► Possible mismatch between assessed spatial skills & those needed to solve given problems
  - Future Research: Does the skill assessment format play a role in the observed discrepancies?
  - **Teaching Practice**: Practice in producing drawings
  - **Teacher Education**: Strategies for developing/utilizing spatial interpretation skills & skills in producing drawings

► Relationship between verbal and logical/analytical skills
  - Future Research: Measured separately (varying effects on problem-solving performance)
Implications (cont’d)

- Interpretation of students’ responses on problem-solving assessments
  - Teaching Practice: Analysis and interpretation of student responses (interviews); develop multiple ways of expressing math ideas
Implications for Differentiated Instruction

► Effective differentiated instruction requires a clear understanding of where each student is
► Assessment-driven data is of utmost importance in the design of effective differentiated instruction
► Cognitive styles affect how individuals process information, and
► They also affect the types of tasks that they find difficult/easy (Sternberg & Zhang, 2001)
Regardless of cognitive style, individuals can use either mode of representation if they make a conscious choice (Sternberg & Zhang, 2001).

Educational focus should not necessarily be on who has/does not have a particular ability, but on how to capitalize on individual strengths, and how to develop learning potential.
Questions?