Spatial Ability Measurement in an Introductory Graphic Communications Course

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Abstract

Research on spatial ability indicates that many spatial test(s) have been used in research areas associated with engineering and technical visualization. A literature review of spatial ability testing produced a list of 24 tests that was used in a survey of EDGD members to identify their preferred tests. The top three identified tests were the Mental Cutting Test (MCT), Mental Rotations Test (MRT), and Purdue Spatial Visualization Test: Visualization of Rotations (PSVT: VR). During the spring of 2012, data were collected from three sections of an introductory graphics communications course (hereafter referred to as an introductory course) at a large university in the Southeastern United States. Data included scores from the MCT, MRT and PSVT: VR and participant demographic information used in this research. This study examined correlations between the three identified tests, the measurement of spatial ability between novice and experienced spatial ability learners, and recommendations for further research. The correlation results were positive between spatial tests although varied in correlation strength (strength of linear association). These results are similar to other reported correlation findings. The spatial learner results show experienced learners have higher spatial ability scores on the three spatial ability tests than novice learners. It is the hope of the researchers that this study will start the inquiry into which visualization tests are best used in determining visual capabilities for students taking our classes.

Introduction

In *Theories of Human Communications*, Littlejohn and Foss [1] discussed the importance of human communications and noted that human communications have been studied for centuries with a greater intensity since World War I in the scientific areas of psychology, sociology, and anthropology. Laing [2] identified the three forms of human communications as oral, written, and nonverbal (actions), where the visual / graphical realm resides within the written form. The general realm of visual / graphical ability, specifically spatial ability, was the focus of this study.

Published articles on spatial abilities can be found in the fields of psychology [3-4], graphics education, and science, technology, engineering, and mathematics education (STEM) areas [5-6]. Wai, Lubinski, and Benbow's [7] study documented efforts made, since the launch of *Sputnik* (1957), to identify and develop the "personal attributes of scientists and engineers" and to foster their potential (p. 817). These authors identified spatial ability as a major contributor to success in STEM education and occupations. Spatial literature, in these areas of STEM and psychology, has been written from the viewpoint of the researcher as it dealt with spatial ability definitions, tests used for research measurement, and conclusions drawn from the results [8-9]. Miller argued that visualization [graphics education] researchers need to better understand published research and its conclusions [10].

Spatial Ability Research

In the *Engineering Design Graphics Journal for 1936-1978* [11], there were only six articles about visualization or spatial abilities. As the number of published graphics education research increased, *The Engineering Design Graphics Journal for 1975-1996* [12], listed many articles under the visualization, CAD, Graphics, and Modeling headings. According to Miller [10], the first published research article on visualization that related to engineering design graphics did not appear until May 1937 in the first edition of the *Journal of Engineering Drawing*. He went on to discuss the history of engineering graphics education and visualization research from the 1920's until the early 1990's. Hartman and Bertoline [13] stated that "graphics [education] and all that it encompasses is a unique body of knowledge that should be studied, practiced, and scientifically verified" (para. 20). Strong and Smith [14] further stated that "in industrial technology we utilize visualization [spatial ability] in applications such as simulations, multi-media, modeling, and distance education" (p. 2). They further stated that "each person has their own unique visualization [spatial ability] skills" (p. 2).

Students' spatial skills are based on their ability to mentally understand, visualize, and manipulate two-dimensional (2D) and three-dimensional (3D) physical objects or their pictorial representation [15-16]. Specific spatial tests are used to measure this spatial ability skill. Eliot [17] and Eliot and Smith [18] can be considered authorities on spatial ability paper and pencil tests as they

are consistently cited in many graphics education research articles [19-20]. Eliot and Smith obtained, reviewed, and categorized several hundred paper and pencil spatial ability tests in their publication. Several authors have discussed spatial ability from the viewpoint of which test(s) can be used to measure specific factors that support spatial ability development in students [21-22]. McArthur and Wellner [23] went further in their discussion of spatial ability test scores (from both single answer and multiple choice tests) and suggested that they may be used incorrectly to identify whether subjects have or do not have spatial abilities. Currently, there are a large number of available tests that can be used in graphics education/spatial ability research, yet there is no consensus on which test(s) are preferred [18]. Therefore, a need exists to determine which spatial tests are actually used, and which spatial tests are preferred by graphics education researchers. This study addressed this by using a survey to identify the top three spatial tests used by researchers for graphics education research and then used these tests in the analysis of two research questions.

Research Questions

Research articles in engineering design graphics encompass a variety of research interest with many researchers using spatial ability tests in their analysis. Interest areas include areas such as prior experience on spatial tests results [24-25], spatial test modification [26], student assessment [5,27], and spatial ability development [28-29].

This research studied student spatial ability in an introductory graphic communications course in engineering design graphics using the three selected spatial ability tests and student demographics information which was obtained from an online survey discussed in the methodology section. The research subjects were students in an introductory graphic communications course (spring semester, 2012) in engineering design graphics.

Considering the three identified preferred spatial ability tests, (the MCT, the MRT, and the PSVT: VR), from the Engineering Design Graphics Division (EDGD) survey, the discussion of the varied spatial ability tests available to graphic education researchers [17-18], and the different tests that have been used in the graphics education research literature, two research questions were investigated in this study.

Research question 1: Are there any statistical correlations that exist between the three spatial ability tests, MCT, MRT, and PSVT: VR for students enrolled in an introductory graphics communications course?

Research question 2: Do students with prior graphics training/experience have better spatial abilities (as measured by higher spatial test scores) than novice students (students without prior training or experience)?

Limited literature was located that utilized spatial ability tests that dealt with these research questions. To that end, a correlation analysis between the three spatial ability tests was conducted to provide information on spatial test(s) that may be used for evaluating spatial ability of students in an introductory graphic communications course in engineering design graphics. Additionally, this study investigated the spatial ability relationship between novice and experienced spatial learners as measured by the three spatial ability tests. For the purpose of this study, a novice learner has not received any job related training (such as co-op) or taken any courses in graphics related subjects that dealt with orthographic and pictorial projection by either sketching or drawing via manual or computer generation. An experienced learner has received at least some limited job related training or taken at least one secondary or post secondary course on graphics related subjects.

Methodology

The research methodology for this study comprised four steps. Each step represented a main topic area that was used in the development of this study's overall research sequence.

The first step covers survey development and approval. This step had three components. The first component involved the development and administering of the EDGD member spatial test preference survey to the 2011 EDGD membership (conducted via a listserve, and the online SurveyMonkey® website). For component one, a review of articles from 1996 to the present in the graphics education field shows that articles are predominantly published in journals from ASEE titled *Journal of Engineering Education,* the EDGD of the ASEE titled *Engineering*

Design Graphics Journal, and the *Journal for Geometry and Graphics* as well as conference proceedings from ASEE and EDGD [11-12,30]. A review of these sources identified ten spatial ability tests from several principal researchers with at least one published research article that specifically utilized spatial ability tests and included a discussion of their research results. An additional review of the spatial ability tests available through the *Educational Testing Service* (ETS) provided an additional listing of tests that graphics education researchers may use. A compilation of tests from these sources resulted in a final list of 24 spatial ability tests that are available for graphics education researchers. This combined list was used in an online survey to investigate the spatial ability tests that members of EDGD preferred. From the survey results, the top three preferred spatial ability tests were the Mental Cutting Test [31] (MCT, Figure 1), Mental Rotation Test by Vandenburg and Kuse [32] (MRT, Figure 2), and the Purdue Spatial Visualization Test: Visualization of Rotations [33] (PSVT: VR, Figure 3) that was used in this study. The second component concerned the development of the student experience and previous training demographics survey given to the subjects of the course sections used in this study (conducted via the online SurveyMonkey® website). This survey provided information that was used in the analysis of research question 2. The third component concerned the review and approval process by the Institutional Review Board (IRB) that is required prior to conducting research using test subjects.
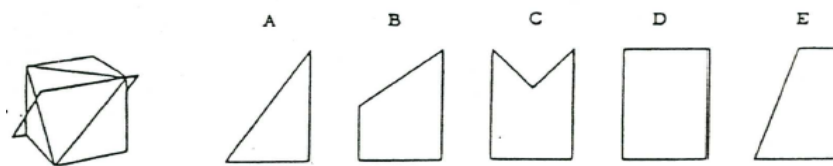

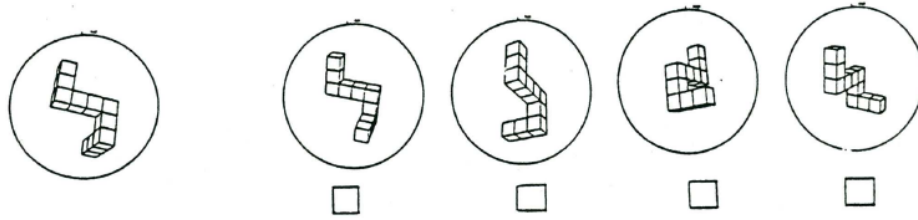Figure 1. A Problem Example from the MCT
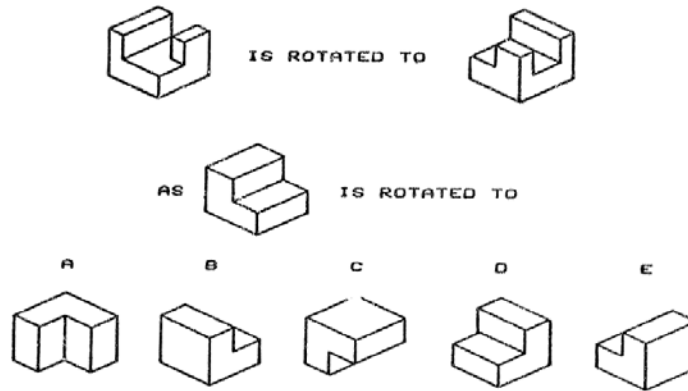
Figure 2. A Problem Example from the MRT

Figure 3. A Problem Example from the PSVT: VR

The second step covered the introductory course sections selection process for the sections used in this study. All sections were reviewed for availability (time and day of class meetings) and sample size potential (number of students in each class section). Once approved by the administration, negotiations between the researcher and the selected section instructors followed. The negotiations concerned the content of the IRB consent form, student demographic survey, the three spatial ability tests, and the specific testing/survey dates/times used in their classes. It was important for the selected section instructors to understand the research intent and sequence in order to ensure a smooth data collection process. All sections used conformed to a face-to-face format [34]. These sections were night classes which met once per week.

The third step concerned the review and signing by each research subject of the IRB consent form prior to testing. A specific spatial ability testing sequence, for the three introductory course sections (Table 1), was designed which varied from section to section. By using this design sequence, student pretest sensitization between the three tests was minimized, which prevented

test data contamination. The test subjects were fully instructed on each test's requirements before the start of each test. The introductory course Moodle[TM] course management software structure was used for all sections in this study. Moodle[TM] management software provided a structured sequence of instruction that was followed by all introductory course sections in this study and provided the link for student survey and access to all the tests.

Course Sections	MCT	MRT	PSVT: VR
00A	administered 1st	administered 2nd	administered 3rd
00B	administered 3rd	administered 1st	administered 2nd
00C	administered 2nd	administered 3rd	administered 1st

Table 1. Research Design Table

The fourth step concerned the data accumulation and analysis portion of the research. The student demographic survey responses were obtained from the three introductory course sections, as was the spatial test scores, and compiled for research question 1 and research question 2 statistical analyses.

Results

This section presents a review of the data collected during the spring semester of 2012, analyzed, and summarized in this study. The data was collected from the study participants (N = 100) in an introductory graphic communications course in engineering design graphics. The specific data collected and analyzed was student participants' demographics data and test scores from three spatial ability tests. Each course section was a small convenience sample; therefore, non-parametric tests were used for all spatial ability test score analysis [35]. The non-parametric tests used in this study were taken from Sheskin [36]. The level of significance used for all hypotheses testing was $p \leq .05$. Table 2 shows the statistical data for all three spatial ability tests.

Test	N	Tests Not Taken	Mean	Median	Min	Max	SD
MCT	99	1	11.929	12.00	3.00	25	5.051
MRT	99	1	27.97	30.00	2.00	40	9.357
PSVT: VR	98	2	21.43	22.00	0.00	30	6.236

Table 2. Statistics for Spatial Ability Tests for All Sections

Internal test Consistency

According to Gall, Gall, and Borg [37], "internal consistency is an approach to estimating test score reliability [coefficient results] in which the individual items of the test are examined" (p. 197). Kuder-Richardson formulas K-R 20 can be used for this evaluation where test items are scored dichotomously [38]. All spatial ability tests used in this study were scored dichotomously; therefore, the K-R 20 formula was used in calculating internal consistency. The calculated K-R 20 coefficients are: MCT (.815), MRT (.868), and the PSVT: VR (.888).

Research Question 1 – Spatial Ability Test Correlation

Sheskin [36] presents the Spearman's rank-order correlation coefficient non-parametric test (test 29) that uses rank ordered data for the correlation analysis between two sets of data. As discussed by Greene and D'Oliveira [39], Spearman's non-parametric test is used for the correlation between a test subject's score on two different tests. There is not a non-parametric test for calculating all three correlation variables (different tests) simultaneously [39]. The Spearman's rank-order correlation coefficient, r_s, measures the correlation between two sets of different test scores.

The null hypotheses were that there was no correlation between each spatial ability test pair analyzed. Based on the results the null hypotheses, H_0, for all combinations of spatial tests are rejected. The alternate hypotheses, $H_1 : r_s \neq 0$, are accepted given that all correlations are positive and not equal to zero. The results were H_1 MCT/MRT $: r_s = .351$, H_1 MCT/PSVT: VR $: r_s = .599$, and H_1 MRT/PSVT: VR $: r_s = .647$.

In 1992, Suzuki, Shiina, Makino, Saito, and Jingu [40] reported correlations between the MCT and the MRT of 0.43, 0.42, and 0.58 for studies at three universities which is similar to the correlation result found in this study (.351). Sorby [41] reported a correlation from a 1999 study between the PSVT: VR and the MCT of 0.528 which is similar to the correlation result found in this study (.599). In 2000, Branoff [26] reported a correlation between the MRT and PSVT: VR of .67 that provides support for the correlation of .647 found in this study.

These correlation results, although positive but varied in correlation strength (strength of linear association) are similar to the other reported correlation findings.

Research Question 2 – Novice and Experienced Spatial Ability Learners

The Mann-Whitney U (non-parametric) test is used for the analysis of two independent samples where there are two populations with different medians, Θs [36]. The requirement of different subjects is based on test subjects that can only be in one condition, which precludes being in the other condition. Greene and D'Oliveira [39] discussed the Mann-Whitney U test as the only non-parametric test for use where there are two conditions (novice versus experienced learners) and different subjects. Based on the student response to the question regarding novice or prior training, the test subjects were assigned to one category only. The analysis for the novice versus prior training learner question using all three spatial ability tests was a one tailed test where $H_1 : \Theta_1 < \Theta_2$ given that the test is for experienced learners having higher test scores than novice learners.

The results from these calculations are that the null hypotheses (example: $H_0 : \Theta_{MCT / novice} = \Theta_{MCT / exper}$) are rejected. The alternate hypotheses (example: $H_1 : \Theta_{MCT / novice} < \Theta_{MCT / exper}$) are accepted. The calculated one tail hypothesis results for the MCT was .011, the MRT was .0495, and the PSVT: VR was .0017. These results show experienced learners have higher spatial ability scores on the three spatial ability tests (MCT, MRT, and PSVT: VR) than novice learners. Table 3 presents the statistical breakdown by spatial test for novice and experienced spatial learners.

MCT	N	Missing*	Mean	Median	Min	Max	SD
Novice	70	1	11.07	11.00	3.00	24.00	4.631
Experienced	28	0	14.18	13.00	4.00	25.00	5.471

MRT	N	Missing*	Mean	Median	Min	Max	SD
Novice	70	1	27.17	28.00	2.00	40.00	9.799
Experienced	28	0	31.21	32.00	6.00	40.00	6.191

PSVT: VR	N	Missing*	Mean	Median	Min	Max	SD
Novice	70	1	20.65	21.00	7.00	30.00	6.357
Experienced	28	1	24.19	26.00	0.00	30.00	4.429

Test grades were included only when experience level was identified
*Missing test score data due to participant not taking the spatial test.

Table 3. Statistics of Spatial Ability Tests by Learner Type

Conclusions

The discussion on conclusions is divided into three areas. First, the EDGD online survey was a listing of 24 spatial tests including some tests that were only mentioned but not actually used in the reviewed graphic research literature. The listing could be reviewed to include only tests used in graphics education research for an EDGD membership re-evaluation. This final listing should also include a test item example for each spatial test which would provide visual information for unfamiliar tests to the EDGD participants. Second, given the discussion on Suzuki, Shiina, Makino, Saito, and Jingu's [40] interpretation that the MCT evaluates some form of spatial ability, but they were unsure what characteristic the MCT was evaluating and their evaluation by extension may also apply to the MRT and the PSVT: VR. An extensive review of the literature on spatial ability factors, starting with Carroll's [21] publication, could be undertaken to ensure that the factors evaluated by each spatial test is accurately known. This knowledge will allow for the use of compatible tests (measuring the same factors) and avoid comparisons across mixed spatial factors. Finally, this study's research results indicated experienced learners have higher spatial ability scores on the three spatial ability tests than novice learners. The question is "at what level

of experience and specific type of course(s)" would the experienced learners' test scores differ from the novice learner? One potential area of research is designating spatial learners into more categories than the two used. The experienced category could include a level 1, level 2, and level 3 where each level identifies more advanced education.

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