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ABSTRACT

This study tested a causal model of the development of spatial visualization based on a synthesis of past and present research. During the summer and fall of 1999, 117 third- and fourth-year undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering completed a spatial visualization test and a background questionnaire during one class period. The spatial visualization test included 32 multiple choice items, each involving an object made up of small unit cubes seen from a certain perspective. Students had to determine which of five other objects was the same as the one shown, but from another view. Student background questions highlighted gender, college major, annual family income, ethnicity, handedness, past and present hobbies, parents' occupations, musical training, favorite high school mathematics course, and childhood toys and activities. Data analysis indicated that spatial visualization developed over a period of time as a result of individuals' experience and certain exogenous qualities. Spatial visualization was influenced by childhood experiences, which were influenced by gender, parents' occupations, and family income. Musical experience had a direct influence on visualization. Childhood spatial experiences had a direct influence on visualization. Females in the study were lacking in spatial experiences. (Contains 36 references.) (SM)

Predictors of Visualization: A Structural Equation Model

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Predictors of Visualization: A Structural Equation Model

"The ability to create a mental image of an object and then to manipulate it mentally has significant practical application in fields such as mathematics, physics, architecture, engineering and design" (Rhoades, 1981). Such an ability has been labeled as one's spatial visualization (Ben-Chaim, Lappan, and Huoang, 1986; McGee, 1979). Previous research has indicated that spatial visualization is a necessary ability for success in certain occupations, namely, architecture, mathematics, mathematics education, and mechanical engineering (Battista, 1994; Bishop, 1980; Blade and Watson, 1955; Eisenberg and McGinty, 1977; Harris, 1981; Miller and Bertoline, 1991; Rhoades, 1981).

Spatial visualization has been studied in several contexts: gender, handedness or hemispheric specialization, cultural environment and improvement of visualization skills. Findings from studies focusing on gender have shown that males outperform females on spatial visualization tests (Battistia, 1990; Burnett, Lane, and Dratt, 1979; Linn and Petersen, 1986; Newcombe, Bandura, and Taylor, 1983; Tartre, 1990). However, one study found no gender differences with respect to spatial visualization when engineering students were tested (Jagacinski and LeBold, 1981). The few studies that have examined the relationship between visualization and hemispheric specialization have shown no consistent findings. In some cases, left-handed persons outperform right-handed persons on tests of spatial visualization (Petersen and Lansky, 1974; Yen, 1975). Yet, in other instances right-handed persons outperform left-handed persons (McGee, 1976; McGlone, 1980). Studies that have focused on the impact of the cultural aspects of one's environment on the development of spatial visualization ability indicate that children who grow up in environments that promote participation in spatial activities either in school or at play outside of school or whose parent(s) has an occupation involving spatial ability had higher spatial visualization than children that didn't have these influences (Belz and Geary, 1984; Bishop, 1980; Harris, 1978). Mason (1986) found individuals having musical ability, due to participation in musical activities (singing or playing an instrument) had stronger spatial visualization skills than their counterparts who did not engage in musical activities. Finally, with regards to improving spatial visualization skills, Baenninger and Newcombe (1989) found a reliable relationship between spatial activity participation and spatial ability. The more a subject had participated in spatial activities (playing with blocks, participating in certain sports, drawing in three-dimensions, and others) the higher his/her spatial visualization test score. A number of other studies have indicated that one's spatial visualization can be improved through appropriate classroom instruction and teacher-monitored activities (Blade and Watson, 1955; Burnett and Lane, 1980; Dixon, 1997; Ferrini-Mundy, 1987; Rhoades, 1981). Such instruction might occur in mathematics courses that lend themselves to visual modes of instruction as in geometry, trigonometry, and calculus.

Although there has been a considerable amount of research conducted with respect to various aspects of spatial visualization, limited research has focused on the level of spatial visualization of undergraduates in their third or fourth years of study who are majoring in architecture, mathematics, mathematics education, or mechanical engineering. Thus a study was conducted to develop and test a causal model of the development of spatial visualization based on a synthesis of the findings of past research.

Specifically the following hypotheses were proposed based on previous research and on a causal model. The causal model reflected a synthesis of prior studies focusing on one or more of the background characteristics studied in this inquiry.

Hypothesis 1: Spatial visualization score will be significantly positively correlated with favorite math course, musical experience, childhood spatial experiences, and spatial hobbies.

Hypothesis 2: Favorite math course will be significantly positively correlated with childhood spatial experiences and spatial hobbies.

Hypothesis 3: Spatial hobbies will be significantly positively correlated with childhood spatial experiences, gender, handedness, mom's job, and dad's job.

Hypothesis 4: Musical experiences will be significantly positively correlated with childhood spatial experiences.

Hypothesis 5: Childhood spatial experiences will be significantly positively correlated with gender, handedness, mom's job, dad's job, and family income.

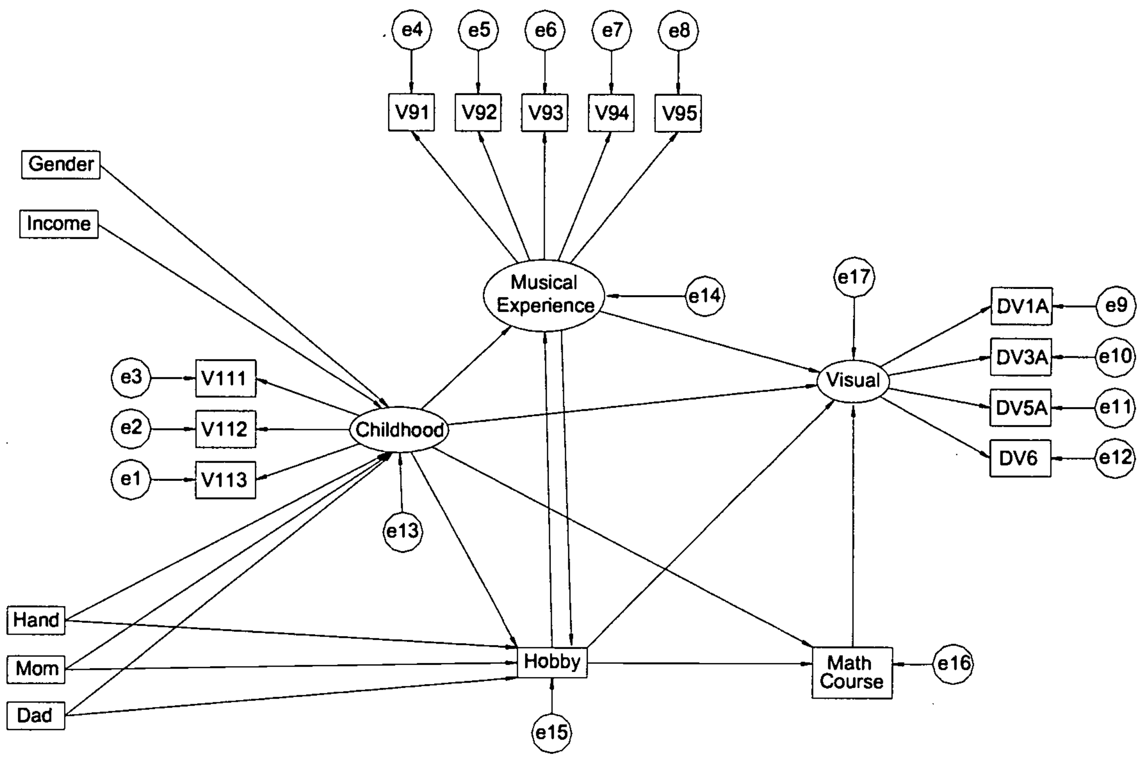


Figure 1. Causal Model

The significance of this study was its potential to provide (1) evidence of the relationships between specific characteristics of students (gender, ethnicity, family income, handedness, parents' occupations, musical ability, hobbies, childhood play experiences, and favorite mathematics course) and spatial visualization ability and (2) a model of the development of spatial visualization that could be tested by other researchers with similar data. Such evidence would benefit middle, high school, and university mathematics curriculum developers for their degree programs.

Methodology

Participants

The study was conducted at a major land-grant university in the southern region of the United States during the summer and fall quarters of 1999. A total of 117 volunteer third- and fourth-year undergraduates majoring in architecture, mathematics, mathematics education, and mechanical engineering participated. Of these 117 undergraduates, 50 were architecture students (43.0%), 19 were mathematics students (16.0%), 24 were mathematics education students (20.5%) and 24 were mechanical engineering students (20.5%). The composition of this sample with respect to gender was 73 male students (62%) and 44 female students (38%).

Procedure

One of the researchers administered a spatial visualization test and a background questionnaire to all students during a class period specific to that major. Data obtained through the Spatial Visualization Test (Middle Grades Mathematics Project, 1983) was used to measure each student's level of spatial visualization ability. The personal background questionnaire was used to determine which variables were significantly related to spatial visualization ability for the entire sample. These background variables included gender, ethnicity, handedness, family income, parents' occupations, musical training, hobbies, favorite high school mathematics course, and childhood spatial experiences.

Instrumentation

The Spatial Visualization Test (Middle Grades Mathematics Project, 1983), used to measure spatial visualization ability, had been used previously with students in grades 8 to 12 and with university undergraduate students. When this instrument was administered with the Differential Aptitude Space Relations Test, the results of the two measures had a correlation of .66, which provided validity of this test. With respect to reliability, Cronbach's reliability coefficients have been found in the range of .72 to .86 for various groups of students taking the test. Since spatial visualization development seems to be determined more by one's "mathematical age" and not by one's chronological age, this instrument was appropriate for this study. The test consists of 32 multiple-choice items, which were to be completed in 15 minutes. Each item involves an object made up of small unit cubes seen from a certain perspective. The student must determine which one of five other objects is the same as the one shown, but from another view. To determine each participant's score on this instrument, the researchers counted the number of correct answers out of 32 possible and converted this to a percentage. Thus, one of the dependent variables for this study, spatial visualization score, defined by the results of this instrument, was continuous on a scale of 1 to 100.

The student background information sheet contained both multiple choice and free-response type questions. Students were instructed to choose only one response for each multiple choice type question. These questions involved gender, college major, annual family income, ethnicity and handedness. The free-response type questions were concerned with past and present hobbies, parents' occupations, musical training, favorite high school mathematics course, and childhood toys and activities. Students were instructed to be as specific as possible in answering these questions.

Data Analysis

A two-step structural equation modeling strategy (Anderson & Gerbing, 1988) via AMOS 4.0 (Arbuckle, 1999) was employed in estimating parameters. This strategy involves the separate estimation of the measurement model prior to the simultaneous estimation of the measurement and structural model. The measurement model provides a confirmatory assessment of the construct validity while the structural model allows a comprehensive assessment of the proposed model.

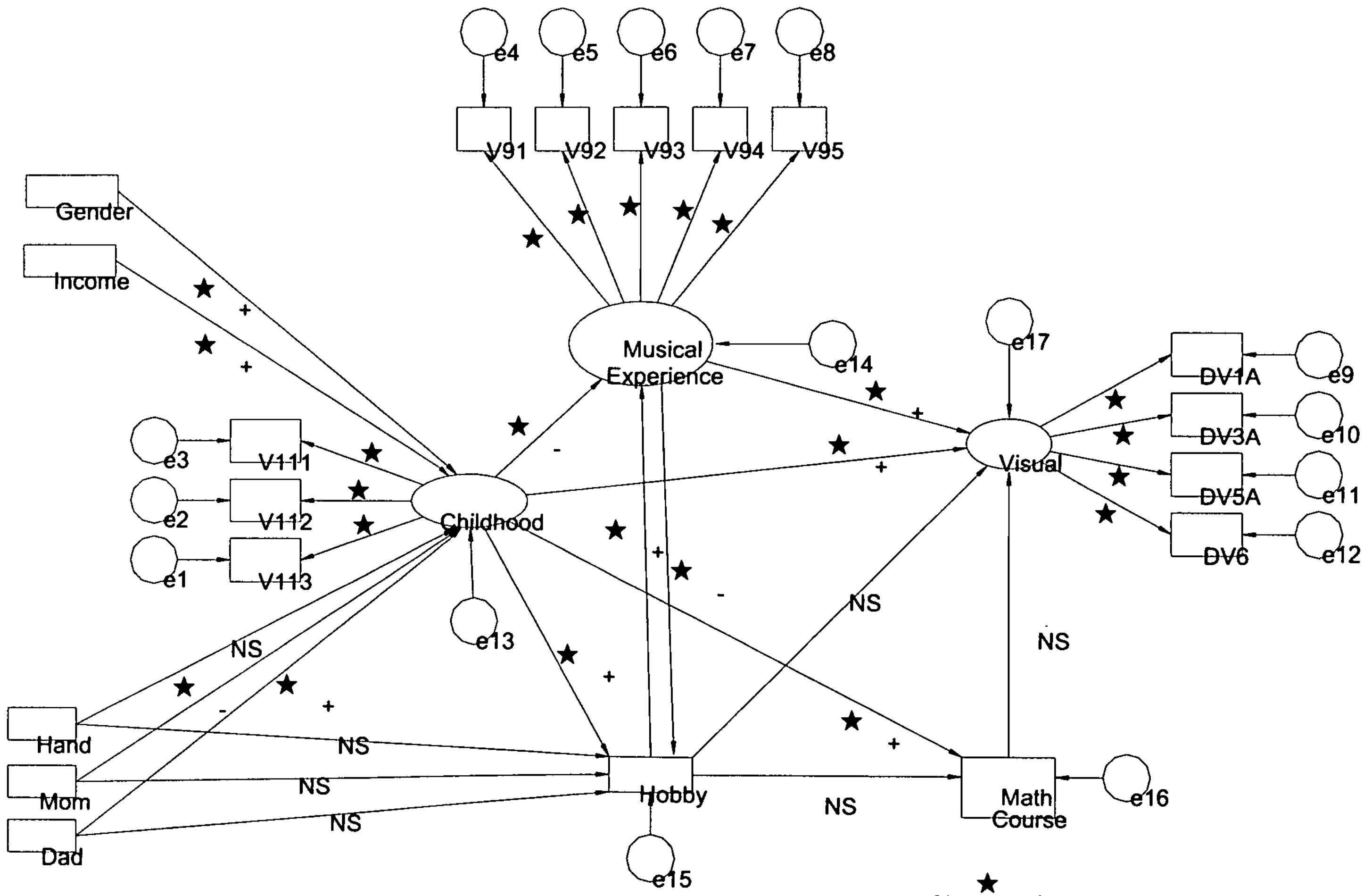
Two methods were employed in judging the goodness of fit of the overall model. First, departure of the data from the specified model was tested for significance by using a chi-square test (Jorekog and Sorbom, 1989). Second, goodness-of-fit between the data and the specified model was estimated by employing the Comparative Fit Index (CFI) (Bentler, 1990), the Tucker –Lewis Index (TLI) (Bentler and Bonett, 1980), and the Root Mean Square Error of Approximation (RMSEA) (Brown and Cudeck, 1993).

Results

The results of all three measurement models (childhood experiences, musical experiences, and visualization ability) provided good support for the a priori model. The goodness-of-fit indices were good in relation to baselines of acceptable fit.

Figure 2 displays the structural coefficients for the integrated model. An asterisk represents the hypothesized effects that were found to be significant.

Although the chi-square test was significant, $\chi^2 (142) = 193.38$, $\underline{p} < .01$, the model yielded acceptably high goodness of fit indices (.981 and .975) for both the CFI and the TLI respectively. Joreskog and Sorbom (1978) and Bentler (1992) advised against the sole use of the chi-square value in assessing the fit of the model because of the sensitivity of the chi-square to sample size. The RMSEA achieved a value of .056 indicating a close fit of the model in relation to the degrees of freedom. The hypothesized model accounted for 58% of the variance for visualization ability.



★ Note: significant at the .05 level

Figure 2. Results of Tested Model

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Discussion

The primary objective of this research was to provide a theoretical explanation of the development of spatial visualization abilities. The variables chosen could easily be available for any institution (middle, high school, or college) and were considered, through previous research, to provide a significant level of predictability. This study confirmed the theories of Harris (1978), Belz and Geary (1984), and Baenninger and Newcombe (1989) in that spatial visualization develops over a period of time as a result of one's experiences and certain exogenous qualities. Moreover, spatial visualization was influenced by one's childhood experiences, which were found to be influenced by one's gender, parents' occupations and family income.

Musical experience had a direct influence on visualization. This provided support for previous research, which hypothesized, that the ability to recognize, execute or create a melodic pattern is a spatial ability similar to the mental rotation of a three-dimensional object (Harris, 1978; Mason, 1986). Childhood spatial experiences had a direct influence on visualization, which confirmed the theories of Sherman (1967) and Baenninger and Newcombe (1989). Their theories claimed that spatial visualization is enhanced by participation in spatially oriented activities such as model building, playing with blocks, drawing three-dimensional objects and playing sports.

Although the researcher expected not to find any significant gender differences due to the selection of the sample, the significant influence that gender had on childhood spatial experiences may help explain why there were so few females majoring in these areas available for this study. The significant influence that family income had on visualization may indicate that children of families with high incomes provide their children with more spatially oriented toys (blocks, "Lincoln Logs", etc.) than children of families with lower incomes. Therefore, these children have more childhood spatial experiences. Finally, the positive influence of father's occupation on the child's spatial experiences supported previous research findings. These findings suggested that one's environment plays a role in the development of spatial visualization (Belz and Geary, 1984; Baenninger and Newcombe (1989); Sherman, 1967).

Because of the significant influence of gender on childhood spatial experiences, in favor of males, the researchers concluded that elementary teachers should ensure that females "play" with spatial toys and engage in other spatial activities, such as participating in sports or music, since the females in this study seem to have been lacking in spatial experiences. Additionally, mathematics teachers at all levels should provide their students with opportunities to engage in spatial activities since the model indicates that one's level of spatial visualization is influenced by his/her experiences. In this way, the likelihood of students entering degree programs in architecture, mathematics, mathematics education or mechanical engineering is great that they will have the spatial visualization skills needed to succeed in their careers.

The researchers suggest that further research be conducted with respect to the relationship between musical ability and spatial ability. Since musical experience significantly influenced visualization, research is needed to determine what specific part(s) of musical ability enhances one's spatial visualization. The researchers also recommend that studies be conducted which focus on the use of visualization in the teaching practices of pre-service mathematics education majors and the impact of these practices on the spatial visualization of their students. Lastly, the model presented should be tested again on a sample similar to the one studied here and on a sample of randomly selected college students. This would not only confirm the model with respect to the majors studied here, but could possibly confirm the model in general.

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