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Advanced Constructional Play with LEGOs Among Preschoolers as a Predictor of Later School Achievement in Mathematics

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The research question asked was "Will those children ages three and four who have intensive play experiences in play-based preschools and who can perform at high levels of LEGO building as constructional play also show high levels of mathematical achievement later in formal school settings?". Thus, this study attempts to establish a correlation between the levels of LEGO play performance of young children and their later school (elementary, middle, and high school) achievement in mathematics. The predictor variables of levels of LEGO play, while controlling for IQ, and gender, were measured in Fall 1982 by testing a group of 3-year-old and 4-year-old preschoolers ($n = 47$), and later, longitudinal effects were examined after these same participants had completed high school ($n = 37$). The dependent or outcome variables obtained from the participants' school cumulative records included: (1) results from the California Achievement Test, (2) the grades in mathematics courses, and (3) higher mathematics courses taken in high school.

LEGO performance during the preschool years and the later variables of students' letter grades, and mathematical achievement on standardized tests did not demonstrate significance at the third and fifth grade levels. At the same time no significance was found at seventh grade levels on teacher-awarded grades, but a clear significance was found for standardized testing at the seventh grade level. Also, since all other outcome variables at the middle school and high school levels such as number of mathematics classes taken, number of honors mathematics classes taken, average mathematics grades, and a combined weighted value of all mathematics courses taken were all significant, we may clearly state that there is a statistical relationship between early LEGO performance among preschool and achievement in mathematics, not seen during the elementary school years, but later developing at the middle and high school level.

Keywords: Constructional play; Preschoolers; Mathematics

INTRODUCTION

Play has historically been a central activity in developmentally appropriate preschools and day care centers for children younger than age 5 (Hartley, Frank, and Goldenson, 1957, Isaacs, 1933). The publication of the seminal work of Smilansky (1968) inspired countless studies over many years to reveal relationship between play and IQ (for example, Johnson, Ershler, and Lawton 1982), performance on conservation tasks (Golomb and Cornelius, 1977), measures of problem-solving (Pepler and Ross, 1981), creativity (Dansky and Silverman, 1975), language acquisition, and social competence.

The generally accepted definition of play includes three large categories: (1) sensori-motor play (large and small motor activity); (2) symbolic play, which involves representational

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abilities and includes the fantasy play of socio-dramatic play; and (3) construction play, which involves symbolic product formation with LEGOS, blocks, carpentry, and similar materials (Piaget, 1962; Smilansky, 1968; Wolfgang and Wolfgang, 1999). Although there is a host of empirical research on symbolic play (Cook, 1996; Dodge and Frost, 1986; Fein, 1981; Pellegrini, 1980), the literature regarding construction play, especially longitudinal studies, is limited (Miller and Bizzell, 1983).

Playing with block-like materials as construction play has been seen for hundreds of years, which has been documented by as educators as early as Pestalozzi (1898). Later, Froebel's (1889, 1895) "gifts of knowledge" were primarily small blocks used to teach mathematics, such as geometric forms and their relationship to one another, through pattern making and block play. Playing with LEGOS as a more modern version of constructional block play has a modern tradition and has been a central play activity found in play preschools (Hirsch, 1996; Provenzo, 1983), with play preschool programs dedicating large amounts of money for purchasing these LEGO blocks and providing classroom time and space to facilitate LEGO play among young children (Wolfgang and Wolfgang, 1999).

There is a large body of research on block play (Provenzo, 1983), and block play as a manipulative activity to teach mathematics concepts (Cartwright, 1971; Henniger, 1987; Hirsch, 1996; Kamii, 1972, 1982; Liedtke, 1995; Riefel, 1983; Vondrak, 1996), but similar studies specifically looking at LEGO forms of block play are limited (Scrniati, 1996; Taylor, 1986; Wiencek, 1987).

Playing with LEGOS, as a form of constructional block play (Piaget, 1962), requires the young child to build spatially with large numbers of LEGOS bricks made of plastic with peg and hole connectors to produce representations of objects, or products. These products at the higher levels of LEGO building can be labeled as imaginary structures representing real objects (Hirsch, 1996; Lunzer 1955). The construction play with LEGOS offers the preschool child the opportunity to classify, measure, order, count, use fractions, and to become aware of depth, width, length, symmetry, shape, and space (Ginsburg, 2000; Hirsch, 1996); thus, one can make the direct relationship with the skills acquired in LEGO play as foundational for later cognitive structures (Kamii, 1972, 1982; Piaget and Szeminska, 1952) needed for number and mathematics skills and learning (Liedtke, 1995; Reifel, 1983; Vondrak, 1994). The question can be asked, "Do those children ages three and four who have intensive play experiences in play-based preschools and who can perform at high levels of LEGO building also show high levels of mathematical achievement later in formal school settings?". Thus, this study attempts to establish a correlational connection between the levels of LEGO play performance of young children and their later school achievement in mathematics.

METHOD

This correctional study, with the use of statistical regression, attempts to establish a relationship between preschool-aged children's levels of LEGO block play with later school achievement in mathematics at the elementary, middle, and high school levels of performance, while controlling for IQ and testing for the effects of gender.

Participants

The participants were selected in 1982 as an intact group of preschoolers enrolled in a later accredited NAEYC play-based preschool located in a southeastern city of the US with a population of approximately 212,000 people, 41.2% of whom were employed in government-related fields. In 1998 the school records of these same participants were obtained after they

TABLE I A Comparison of Demographics on Participants at Preschool and High School Levels

	Participants as of 1982 (preschool)	*Participants as of 1999 (graduating high school)*
Number of participants:	37	27
Age range	3 years 10 months to 4 years 11 months	18 years 10 months to 19 years 11 months
Racial mix		
Caucasian	74%	85%
African American	17%	15%
Asian American	9%	0%
Gender		
Males	51%	52%
Females	49%	48%
Age at entry		
Before age 1	42%	55%
Before age 2	34%	20%
Before age 3	17%	15%
Before age 4	7%	10%
Socio-economic status		
Level 1 (lowest)	20%	Not available
Level 2	29%	
Level 3	36%	
Level 4	11%	
Level 5 (highest)	3%	
Type of school		
Public school	–	81%
Private school	–	4%
University laboratory school	–	15%
Post-secondary education		
Attending	–	65%
Not attending	–	17%
Unknown	–	8%

had completed high school to permit a longitudinal comparison. Table I presents characteristics of participants in 1982 (when their LEGO-building abilities were measured) and in 1998 (when the longitudinal data was captured).

Ten participants (32%) were lost, with five not being located and five not responding after three attempts. The racial mix of the lost participants were six Caucasians, two African-Americans, and two Asian-Americans. Of these, four were males, and six were females.

Instrumentation

Lunzer Five-Point Play Scale

The Lunzer (1955) Scale, based on the Piagetian theoretical framework, was used to rate the preschoolers' "adaptiveness" in the use of LEGOS and "integration" or play complexity on a five-point scale. The low score (1) would be defined as "the materials [LEGOS] are used without regard to their physical or representational properties". The highest score of 5 would be defined as "the materials [LEGOS] are used in a highly insightful manner, adapted to a concept that clearly transcends it". The Lunzer research reports a 0.91 reliability with similar age participants, while this research produced a 94% interjudgmental reliability.

McCarty Scales of Children's Abilities

A general cognitive score, or IQ, was attained from summing the verbal, perceptual performance, and quantitative scores on the McCarty Scales of Children's Abilities (McCarty, 1972), which was administered individually to the participants at the preschool center by a university professor in early childhood education. The raw subscale scores were used because the indexed scores were normed by age level and would therefore have reduced variance across participants.

The California Achievement Test

The California Achievement Test (CAT) was administered by school officials as the normal routine of standardized testing beginning in Grade One though Grade Eight. The CAT score was the mathematics computation and mathematical concepts using the national percentile score ranging from 1 to 99 points. Scores obtained at Grade Three, Grade Five, and Grade Seven were used for computational purposes.

Mathematics Grades

Report card letter grades in mathematics taken from the participants' elementary records (Grades One through Five) were scaled as 0 (U, unsatisfactory), 1 (N, needs improvement), 1.5 (S minus, satisfactory), 2 (S, satisfactory), 2.5 (S plus, satisfactory), and 3 (E, excellent). Letter grades in mathematics taken from the participants' middle school records (Grades Six through Eight) were scaled as 0 (F, failure), 1 (D, below average), 2 (C, average), 3 (B, above average), and 4 (A, excellent).

Higher Mathematics Courses, Taken in High School

From high school records for the ninth through twelfth grades, higher mathematics courses (algebra 1, 2, and 3; algebra 2 honors; mathematical analysis; geometry; geometry honors; analytical geometry; trigonometry; calculus; advanced placement calculus; and advanced placement statistics) were counted, with heavier weightings given to "honors" courses. The score for the variable "higher mathematics courses taken" was obtain by adding the number of courses with a score of 1 for regular mathematics courses. A second variable was established comparing the number of honors courses taken. Finally, a weighted combined point value of mathematics courses taken was determined by summing all courses taken and giving a score of 2 for those labeled as honors and advanced courses.

Procedures

The predictor variables of levels of LEGO play, IQ, and gender were measured in Fall 1982 by testing a group of 3-year-old and 4-year-old preschoolers, and later, longitudinal effects were examined after these same participants had completed high school. Their accumulative school records containing participants performance at the elementary, middle, and high school levels were obtain in 1998.

During the preschool phase of data gathering, the participants were rated by a researcher, who was trained and who had demonstrated an interjudgmental reliability of 94%, with the use of Lunzer Five-Point Play Scale (Lunzer, 1995). This scoring was done while each participant was engaged in LEGO play on three different days in the natural classroom setting as a part of their normal school day without any facilitation from their teacher. Participants were simply instructed by the teacher at the beginning of the play session, "Do the best LEGO play that you can do today, and use as many LEGOS as you can!". Attempting to obtain the highest level of performance, the researcher used the best of the three scores as the independent or predictor variable.

Because IQ has been determined to correlate with and accounts for the large percentage of the variance in play research (Smilansky, 1968; Smilansky and Shefatya, 1990) and school achievement in mathematics (Aiken, 1976; Campbell and Ramey, 1995), the researcher also administered the McCarty Scales of Children's Abilities (McCarty, 1972) to obtain an IQ score. Since gender has also been shown to be correlated with various play abilities and mathematics (Casey, Pezaris, and Nuttall, 1992; Fennema, Carpenter, Franke, Levi, Jacobs, and Erupson, 1996; Fennema and Sherman, 1978; Leder, 1985; Leder and Fennema, 1990; Meyer and Koehler, 1990), gender was established as a dichotomous variable. The dependent or outcome variables obtained from the participants' school cumulative records included: (1) results from the CAT, (2) the grades in mathematics courses, and (3) higher mathematics courses taken in high school.

Statistical Analysis

Using the Statistical Package for Social Science, two statistical analyses were used in this study – hypotheses that state a relationship were tested with simple regression, while those requiring control for IQ and gender used multiple regression.

RESULTS

The Elementary Grade Levels

The third grade data comparing LEGO performance and standardized test scores indicate a correlation of 0.800 with $p = 0.376$, and LEGO performance and mathematics grades correlated at 0.1615 with $p = 0.283$ (see Table II). This indicated no statistical significance at the third grade level for grades and standardized test scores. The fifth grade data comparing LEGO performance and standardized test scores indicate a correlation of 0.3354 with $p = 0.080$, and LEGO performance and mathematics grades correlated at 0.4104 with $p = 0.029$. This indicated no statistical significance at the fifth grade level. The seventh grade data comparing LEGO performance and standardized test scores indicate a correlation of 0.0690 with $p = 0.380$, and LEGO performance and mathematics grades correlated at 0.2155 with $p = 0.162$. This indicated no statistical significance at the seventh grade level.

Using a hierarchical multiple regression with step by step entering of IQ and gender, and then the play variable on LEGO performance, the F score was used to determine statistical significance at the 0.05 alpha level. At the third grade comparison, a significant $F = 0.4761$ between LEGOS and standardized test scores indicates no statistically significant relationship. Again, in a like manner, a significant $F = 0.9575$ for LEGOS and

TABLE II Correlation Matrix of Grades 3, 5, 7: Mathematics and LEGOS

	Mathematics standardized test score			*Mathematics grade*		
	Grade 3	*Grade 5*	*Grade 7*	*Grade 3*	*Grade 5*	*Grade 7*
LEGOS	0.800 ($p = 0.376$)	0.3354 ($p = 0.080$)	0.0690 ($p = 0.380$)	0.1615 ($p = 0.283$)	0.4104 ($p = 0.29$)	0.2155 ($p = 0.162$)

TABLE III Multiple Correlation Coefficients: Matrix of Grades 3, 5, 7, Mathematics and LEGOS

	Significant F *values*					
	Mathematics standardized test score			*Mathematics grade*		
	Grade 3	*Grade 5*	*Grade 7*	*Grade 3*	*Grade 5*	*Grade 7*
LEGOS	0.4761	0.3509	0.0259*	0.9575	0.6865	0.4008

*Significant at alpha level 0.05.

grades indicated no statistically significant relationship while controlling for IQ and gender (Table III).

Using a hierarchical multiple regression, the fifth grade data produced a significant $F = 0.3509$ between LEGOS and standardized test scores, indicating no statistically significant relationship. Again, in a like manner, a significant $F = 0.6865$ for LEGOS and grades indicates no statistically significant relationship while controlling for IQ and gender.

At the seventh grade level, the significant $F = 0.3517$ indicates no statistically significant relationship for the controlling of IQ and gender. Using a hierarchical multiple regression, the significant $F = 0.0259$ between LEGOS and standardized test scores indicates a statistically significant relationship. Again, in a like manner, a significant $F = 0.4008$ for LEGOS and grades indicates no statistically significant relationship while controlling for IQ and gender.

High School Level

The null hypothesis can be stated as follows: "There is no significant relationship, when controlling for IQ and gender, between participants' play level in LEGO performance and (a) number of higher mathematics courses taken in high school, (b) number of honors classes taken, (c) mathematics grades, and (c) weighted combined point value of mathematics courses".

With the confidence level set at 0.05 for LEGO performance during the preschool years and achievement in mathematics at the high school, the number of higher mathematics courses taken produced a significant $F = 0.0078$ and did indicate a statistically significant relationship; thus, the null was rejected. Also, the number of honors classes taken produced a significant $F = 0.0288$ and indicated a statistically significant relationship (Table IV). Also, mathematics grades produced a significant $F = 0.0026$, indicating a significant

TABLE IV Multiple Correlation Coefficients: Matrix of Grades 3, 5, 7, Mathematics and LEGOS

	Significant F *values for High school achievement in mathematics*			
	Number of courses	*Honors courses*	*Mathematics grades*	*Advanced mathematics courses*
LEGOS	0.0078*	0.0288*	0.0026*	0.0077*

*Significant at alpha level 0.05.

relationship. Weighted combined point values were used to obtain a measure of advanced courses in mathematics taken, producing a significant $F = 0.0165$; again this was significant.

In summary, on testing the hypothesis related to LEGO performance during the preschool years and achievement in mathematics in the third, fifth, and seventh grades, through standardized test scores in mathematics and the test scores only at the at seventh grade level when IQ and gender was statistically controlled, the null was rejected and significance was established. When tested for this same relationship related to grades at the same grade levels, no statistically significance was found.

When statistically testing for significant LEGO performance during the preschool years and later achievement in school mathematics (defined as number of classes taken, number of honors classes taken, average mathematics grades and, finally, a combined weighted value of all mathematics courses taken), each of these outcome variables were significant.

DISCUSSION

LEGO performance during the preschool years and the later variable of students' letter grades, which were awarded to them by their classroom teachers, and mathematical achievement on standardized tests did not demonstrate significance at the third and fifth grade levels. At the same time no significance was found at seventh grade levels on teacher-awarded grades, but a clear significance was found for standardized testing at the seventh grade level. Also, since all other outcome variables at the middle school and high school levels such as number of classes taken, number of honors classes taken, average mathematics grades, and a combined weighted value of all mathematics courses taken were all significant, we may clearly state that there is a statistical relationship between early LEGO performance among preschool and achievement in mathematics, not during the elementary school years, but later at the middle and high school level. These results were nearly identical to a parallel study comparing block building among preschool children and mathematics achievement (Wolfgang, stannard, and Jones, 2000). The question is raised as to why we do not see this same significance at the third and fifth grade levels.

One answer is that children near the age of 11, or the beginning of middle school, begin to acquire formal operational thinking (Piaget, 1977), which enables the child to reason in abstract terms and separate from the need for concrete objects. Since the acquisition of knowledge, from a Piagetian framework, is accumulative, drawing on the motor activities of the preoperational years and stages (like LEGO play during the preschool school years and concrete use of objects during the concrete operational period during the elementary school years), we may hypothesize that those preschool age participants that have learned through LEGO play and have demonstrated high levels of performance with LEGO building were developing the basic underlying cognitive structures that would permit them to perform well in higher abstract mathematics such as geometry, trigonometry, calculus, and similar advanced mathematics. This can been seen as early as the seventh grade on standardized tests of mathematics skills in the seventh grade. In turn, grades awarded by teachers and the standardized testing during the elementary years (Grades Three and Five) only test minimum skills and memorization, and thus we find no correlation between elementary mathematics and LEGO performance during this pre-operational period. This may suggest that the real and lasting effects cannot be demonstrated by academic measures during the elementary school years, but can be seen at the beginning of the middle school years. Support for this assertion can be found in the research literature (Schweinhart, 1994; Schweinnart and Weikart, 1997).

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