Running Header: Children's construction performance and math.

Children's construction task performance and spatial ability: Controlling task complexity and predicting mathematics performance.

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Summary - This paper presents a methodology to control construction task complexity and examined the relationships between construction performance and spatial and mathematical abilities in children. The study included three groups of children (N=96); aged 7-8, 10-11 and 13-14 years. Each group constructed seven pre-specified objects. The study replicated and extended previous findings that indicated that the degree of component symmetry and variety, and the number of components for each object and available for selection, significantly predicted construction task difficulty. Results showed that this methodology is a valid and reliable technique for assessing and predicting construction play task difficulty. Furthermore, the study found that construction play performance predicts mathematical attainment independently of spatial ability.

Keywords: Construction play; cognition; mathematics; spatial ability.

Introduction

Construction play is a form of motor skill based play that involves assembling objects with blocks, LEGO™, MECCANO™ or other similar materials. Having children play with these products is an activity that is frequently utilised in schools (Wolfgang & Wolfgang, 1999). As is well known, children's construction play has been linked to later achievements in mathematics and science (e.g., Hanline, Milton & Phelps, 2010; Kersh, Casey, Mercer Young, Spodak, & Saracho, 2008; Wolfgang, Stannard, & Jones, 2003). Kersh, *et al*. reported on the critical role of developing spatial sense in children's mathematics learning and how construction with blocks provides a spatial task that appeals to children. Key to studying development and progression of spatial ability are spatial tasks that can be controlled for complexity. However, much of the research into construction play has focussed on evaluating the products of less structured block building (e.g., Hanline, *et al.,* 2010), rather than on completing specific, complexity-controlled construction tasks. Methods for assessing the difficulty of assembling the objects used in construction play are of value (e.g. Nath & Szücs, 2014), and the research presented here provides a methodology for controlling and manipulating construction tasks while also confirming the link of spatial ability to mathematics. In addition, the present paper demonstrates how assembly performance itself predicts mathematics attainment, independent of spatial measures.

Benefits of Construction Play

Construction play depends upon a range of cognitive abilities, for example, there are distinct cognitive changes (e.g. how the task is organised) in children's block building strategies (Casey, Andrews, Schindler, Kersh, Samper, & Copley, 2008), and play preferences for construction toys have been linked with the development of visuospatial functioning (Brosnan, 1998; Caldera, Culop, O'Brien, Truglio, Alvarez, & Huston, 1999). Importantly, constructional play with LEGO (Wolfgang, *et al.*, 2003), block play (Kamii, Miyakawa, & Kato, 2004), and spatial abilities are all related to, and predict, mathematical achievement (Burnett, Lane, & Dratt, 1979; Casey, Nuttall, Pezaris, & Benbow, 1995; Geary, Saults, Liu, & Hoard, 2000; Robinson, Abbott, Berniger, & Busse, 1996). One hypothesised mechanism for the relationship between construction play and mathematical abilities is that block-type play teaches math concepts (Kersh, *et al.*, 2008). Educational interventions have incorporated block building activities to improve spatial abilities, and found that these tasks lead to improvements in block design, but not mental rotation; the ability to visualize a rotated object (Casey, *et al.*, 2008). These results indicated that block building had a specific effect on spatial visualization skills, rather than on spatial ability, that relies upon visual working memory. More recently, it has been found that cognitive abilities and construction play can explain mathematical performance in 7-years olds (Nath & Szücs, 2014). Using the methodology developed by Richardson *et al.* (2006) and path analysis, Nath and Szücs (2014) showed that the relationship between mathematical performance and construction play ability was mediated by visuospatial working memory and a unique portion of the variance was explained by construction play. However, the extent to which spatial ability and construction play performance independently predict mathematics attainment within a wider age range is not currently known.

Controlled Construction Tasks

As a play based activity, construction tasks provide an excellent opportunity to understand and develop children's spatial sense and thereby their mathematics potential. Methods for assessing the difficulty of assembling the objects used in construction play are therefore of value as they allow children's construction ability to be predicted and controlled, (e.g. Nath & Szücs, 2014). For example, control for complexity, a fundamental issue for dual-task paradigms, and selecting experimental tasks that are age appropriate for research considering developmental progression. Existing research, for example Casey *et al*. (2008), evaluated the complexity of children's block constructions by analysing their structure. This approach typically uses aspects of hierarchical integration and spatial dimensionality for assessing the block play of younger children, and is not focussed on task characteristics that can be manipulated within an assembly type (e.g. 3D horizontal enclosures can vary in complexity). As children's construction play has been linked to later achievements in mathematics (e.g., Hanline, *et al,* 2010; Kersh, *et al*., 2008; Wolfgang, *et al*., 2003) it would be beneficial to quantify children's construction ability through delivering systematic progression in construction complexity from children through to adolescents. The research presented here provides a methodology to do this.

In a series of experiments with adults, Richardson and colleagues (Richardson, Jones, & Torrance, 2004; Richardson, Jones, Torrance, & Baguley, 2006) identified a number of physical characteristics hypothesised to impact on cognitive workload, that relate to construction task difficulty, and which facilitated a quantification and prediction of construction tasks. They found that an increase in construction assembly time was associated with a reduced level of symmetry (which has perceptual and spatial demands), an increased number of components in the assembly, an increased number of components to select from (perceptual demands) and a higher level of component variety, within the context that novelty and complexity are known to be related to motivation to certain thresholds (e.g. Berlyne, 1979).

The first aim of the present study was to extend earlier work in order to examine the application of the construction task characteristics methodology with three age groups of children aged 7 to 14 years and with an additional set of materials as it is good practice to extend findings beyond a restricted set of materials. The second aim was to extend the current understanding of the relationships between spatial ability and mathematical abilities in children and adolescents by considering the role of construction play ability.

Method

Participants

An opportunity sample of 96 participants from three age groups were recruited from local schools within differing socio-economic regions of Derbyshire and Staffordshire, United Kingdom. Each age group comprised 32 participants who had not taken part in previous research by the authors. Half were randomly allocated the previously tested recognisable construction tasks and the other half new abstract construction tasks. The younger group of children was aged 7-8 years (M = 8.11 years, SD = 0.34; 19 boys, 13 girls, the older child group was aged 10-11 years (M = 11.10 years, SD = 0.33; 17 boys, 14 girls), and the adolescent group was aged 13-14 years (M = 14.00 years, SD = 0.31; 10 boys, 22 girls). There was no significant difference between the sexes on spatial ability, p = .99, d < 0.01, but mathematical ability was greater among girls than boys, p = .01, d = 0.52. Ethical approval for the study was provided by the Department of Psychology, University of Derby Ethics Committee. Following agreement with each of the head teachers, appropriate classes were invited to take part and informed consent was provided by each parent or legal guardian, and verbal assent was given by the child prior to testing. The children and adolescents were excused from classes in order to participate in the study and testing was conducted in a quiet area of the schools.

Materials

LEGO Construction Tasks - The construction tasks were based on manipulation of the four significant physical characteristics found to predict construction task difficulty (Richardson, et al., 2006). These were level of symmetry (the mean number of symmetrical planes per component measured in three planes, X, Y and Z), a higher level of component variety which create novel assemblies (the number of unique assembly procedures in a construction), an increased number of components to select from (selections, the total number of components available to select from at the start of the assembly task) and an increased number of components in the assembly. These tasks were designed to control collinearity in the regression analysis and to ensure sufficient independent variability to reveal the separate effects of the variables. To create an orthogonal design the task designs were modified using an iterative process; calculation of construction task variable levels for the assemblies; correlation analysis between task variables; and modification of tasks to ensure a range of variable levels and reduction of high correlations that may arise. Eighteen different single colour LEGO-based construction tasks were used, of which seven are recognisable items of furniture (e.g. table, chair), and used previously (e.g. Richardson et al., 2006). To demonstrate that the approach is not limited to a single set of real-world tasks an additional seven fractional factorial and orthogonal abstract construction tasks were created using the iterative process described above. A further four construction tasks were used as practice items. Table 1 shows the task variable levels for the fourteen, non-practice, assembly tasks. As with typical construction play items, the instructions consisted of exploded isometric views, with a single step, and target diagrams of the completed assemblies (Figure 1).

Table 1 About here

Figure 1 About here

Spatial Ability - The Surface Development Test was used to assess spatial ability and is one of the visualization subtests in the Kit of Factor-References Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976). Visualisation is the ability to manipulate or transform an image of spatial patterns into other visual arrangements. The Surface Development Test involves showing participants a flat shape with numbered sides and a three-dimensional shape with lettered sides and asking the participants to indicate which numbered side corresponds to which lettered side. The test is comprised of six items, each with five questions and a total time of six minutes for completion. The Surface Development Test has been validated in adults (Ekstrom, *et al.,* 1976), found to be reliable (Kuder-Richardson coefficient of 0.84; Goldman, Osborne & Mitchell, 1996; Cronbach alpha of 0.94, Olson, Eliot, & Hardy, 1988), and was shown to be a spatial measure with the strongest correlation to construction task performance in adults aged 18-65 years (Richardson, 2004). To the best of the current authors' knowledge, the current study is the first time the Surface Development Test has been used with children; however, other subtests of the Kit of Factor-References Cognitive Tests have been used with younger populations (see Ekstrom, *et al*., 1976). Initial piloting of the study found that children were able to complete the task and it was scored in accordance with the manual (Ekstrom, *et al.,* 1976); number of correct items completed in six minutes, minus number of incorrect items.

Procedure

Two practice construction tasks were administered to allow the participants to fully understand the task requirements and how the instructions could be used to assist with the construction. Then, the construction tasks were administered with the order randomly allocated prior to testing. Participants used the single step exploded isometric view with target diagram instructions (see Figure 1) to create a matching three-dimensional structure from the components provided. All participants were instructed not to rush, as timings were only used to assess the construction of each of the assemblies. On completion of the construction task, the Surface Development Test was administered.

Data Analysis

Mathematics levels from standard United Kingdom National Curriculum tests known as SATs were provided by the schools and indicated the mathematical ability of the participants. Children are given SATs in a classroom setting at the end of school years 2 (aged 7-8 years), 6 (aged 10-11 years) and 9 (aged 13-14 years). SATs scores increase relative to age, such that 7 year-olds typically achieve at least level 2, 11 year-olds typically achieve at least level 4 and 14 year-olds achieve at least level 6. Construction performance was measured by time taken (in seconds) and position errors; that is the correct component in the correct orientation, but placed in the wrong position.

Tests for parametric assumptions were conducted. As construction time was skewed towards zero, these data were log transformed. To examine the relationship between construction time, and the construction task characteristics, multiple regression models were used for each group. As there were multiple data for each participant, dummy variables, identifying each participant, were entered into the first block in order to control for variability due to individual differences (Pedhazur, 1982). The four construction task characteristics (components, symmetrical planes, novel assemblies, and selections) were entered in the second block. In order to examine whether there were significant differences between the coefficients for each age group, Z-tests were conducted using the equation provided by Paternoster, Mazerole, & Piquero (1998).

Results

Predictors of Construction Performance: Original Tasks

The between-participant dummy variables in model 1 indicated the amount of variance accounted for by individual differences, with the R ranging from 0.48 to 0.57, and the R^2_{adj} from 0.11 to 0.22. As shown in Table 1, the four construction task characteristics predicted construction time in each of the groups and explained 36.6 per cent of the variance in construction time in the 7-8 year-olds, 28.7 per cent in the 10-11 year-olds and 36.7 per cent of the variance in 13-14 year-olds. Each of the construction task characteristics was a significant unique predictor of construction time (all $p < .05$) in all of the age groups. Standardized regression coefficients for each construction task characteristic showed that an increase in construction time was associated with an increased number of components, a reduced number of symmetrical planes, a higher number of novel assemblies, and an increased number of selections (Table 2).

The Z-tests revealed that there were no significant differences between the coefficients in the 7-8 and 10-11 year-olds for any of the construction task characteristics. However, there was a significant difference between the 7-8 year-olds and 13-14 year-olds with regard to Selections ($Z = 2.57$, $p = .010$). There was also a significant difference in Symmetrical Planes between the 10-11 year-olds and the 13-14 year-olds ($Z = -2.55$, $p = .011$). Importantly, the current study showed that the four construction task characteristics predicted construction time in children aged 7-8, 10-11 and 13-14 years. The patterns of these relationships did not significantly differ between these ages.

Table 2 About here

Predictors of Construction Performance: New Tasks

The between participant dummy variables in model 1 indicated the amount of variance accounted for by individual differences, with the R ranging from 0.43 to 0.52, and the R^2_{adj} from 0.06 to 0.15. The overall regression models in each of the groups were significant and indicated that the four construction task characteristics predicted construction time in each of the groups. The amount of variance in construction time explained by the combined four sub-processes was 30.3 per cent, 45.6 per cent and 54.7 per cent for the 7-8, 10-11 and 13-14 year-olds, respectively. However, it was only in the 10-11 year-olds that each of the construction task characteristics was a significant unique predictor of construction time (Table 2). The selections variable was not a unique predictor of construction time of abstract construction tasks in the 7-8 and 13-14 year-olds, and indicated that the total number of selections available did not influence construction time of this type of construction task in those children. Similarly to the previous results, an increase in construction time was associated with an increased number of components, a reduced number of symmetrical planes, and a higher number of novel assemblies (Table 3). The comparison of the coefficients found no significant differences between any of the groups for any of the construction task characteristics, which indicated that the construction of abstract construction tasks was similar across childhood and adolescence.

Table 3 About here

Prediction of Construction Performance

The four construction task characteristic values for each of the construction tasks were entered into the regression equation produced by Richardson, *et al*. (2006) to produce predicted construction times:

Construction Difficulty = $10^{([0.02\text{Components}] + [-0.12\text{Symmetrical Planes}] + [0.05\text{Novel Assemblies}] + [0.03\text{Selections}] + 1.46)}$

This regression equation was based on data collected from adults building the original LEGO models. The predicted construction times were then compared to the actual mean construction times for each of the construction tasks, both original and abstract, for the corresponding age group where possible (Table 4). This analysis produced strong ecological correlations within and between model types [ranging from r (5) = 0.86 to (r (5) = 0.97, all p<.05].

Table 4 About here

Using the pooled data for original and new tasks regression equations for the prediction of construction task difficulty (as measured by time) for each age group were produced:

Age 7-9 years = $10^{([0.05\text{Components}] + [-0.28\text{Symmetrical Planes}] + [0.08\text{Novel Assemblies}] + [0.03\text{Selections}] + 1.38)}$

Age 10-12 years = $10^{([0.05\text{Components}] + [-0.28\text{Symmetrical Planes}] + [0.10\text{Novel Assemblies}] + [0.02\text{Selections}] + 1.43)}$

Age 13-14 years = $10^{([0.04\text{Components}] + [-0.20\text{Symmetrical Planes}] + [0.09\text{Novel Assemblies}] + [0.01\text{Selections}] + 1.37)}$

Relationship between Construction Performance, Spatial Ability and Math Ability.

As there were significant correlations between age, spatial ability and mathematics SATs level, the effect of age was partialled out. There were significant correlations between construction time and mathematical ability and construction time and spatial ability. A hierarchical multiple regression was performed in which math ability was regressed onto the predictors: age, gender, spatial ability, task time, and task position errors. As shown in Table 5, at step one, age and gender explained 74.4 per cent of the variance in math ability. At step two, spatial ability was a significant predictor and explained an additional 9.8 per cent of the variance. Contruction time was added at step three and accounted for an additional 0.7 per cent of the variance in math ability. At step four, position errors explained a small but significant 1.9 per cent of the variance and were negatively related to math ability. Spatial ability remained a significant and strong predictor, being positively correlated with math ability. As a whole, the regression model was significant, explaining 86.8 per cent of the variance in math ability, F (5, 56) = 73.64, $p < .001$, $R^2 = .87$, $R^2_{adj} = .86$.

Table 5 About here

Discussion

Predictors of Construction Performance

The first aim of the research was to investigate the relationship between construction task characteristics and construction task performance during childhood. The study examined whether the four construction task characteristics (the number of components, the mean number of symmetrical planes, the number of unique assembly procedures, and total number of components available for selection) predicted construction task difficulty in children and adolescents. In line with previous studies using this methodology (e.g. Richardson, *et al.*, 2006), the study found that an increase in construction task difficulty was associated with an increased number of components, a reduced number of symmetrical planes, a higher number of novel assemblies, and an increased number of selections. In both types of construction task, the four construction task characteristics together accounted for a significant amount of variance in construction task performance, however the number of components available for selection in the abstract construction tasks was not related to construction time in the 7-8 year-olds and 13-14 year-olds. This finding is likely to be an artefact of the new materials, the abstract construction tasks, as the number of selections variable has consistently been found to be a unique and significant predictor in previous studies (Richardson, *et al*., 2004, 2006, 2011).

The beta coefficients for the number of symmetrical planes significantly differed between the 10-11 year-olds and 13-14 year-olds. This result indicates that any significant increase or decrease in the number of symmetrical planes had a greater impact on construction play task performance in the 10-11 year-olds compared to the adolescents. This shows that different construction task characteristics are more important to construction play complexity at different points in development. This developmental trajectory related to handling of important aspects of construction complexity, such as component asymmetry and variety (novel assemblies) is an area for further research, using controlled materials that adjust the four construction task characteristics independently. As detailed below, the results and method presented provide a unique standardised methodology to do this.

The power of the task characteristics approach to evaluating construction task complexity is demonstrated by their predictive utility. The regression models produced by Richardson, *et al*. (2006) predict the performance of children in the present study very well. This occurs across the three age points and importantly, between construction tasks type; that is data from the original LEGO models predict performance on the new abstract construction tasks. Further, being able to predict performance successfully gives the best sort of reason for accepting the role in construction complexity of the four construction task characteristics (Kaplan, 1964). It is clear that the complexity of objects supplied for construction play can be evaluated, controlled, manipulated and predicted. Furthermore, the consistency of the results using different construction tasks across different age groups indicates that this methodology is a valid and reliable technique for assessing construction task difficulty. Although the regression equation based on adult data was successful, a further three regression equations for each age group are provided for those wanting to predict the rank order of construction task difficulty.

The importance of these findings is that the four construction task characteristics can be used to evaluate construction tasks and instructions used in construction play. A fundamental requirement for dual-task paradigms considering developmental progression is selecting experimental tasks that are age appropriate. The approach outlined here can underpin a range of further research and application in this area, for example it was recently used to by Nath & Szücs, (2014) to develop a series of new construction tasks of ascending difficulty. The iterative process involved in the creation of the construction tasks facilitates the development of a countless number of assembly tasks. This is particularly important if multiple measures of construction task performance are required, for example, pre- and post-test construction play based educational interventions, as parallel forms of items address the influence of carryover effects with repeated testing.

Construction Performance, Spatial Ability and Math

The second aim was to consider the relationships between construction play performance, and spatial and mathematical abilities in children and adolescents. A particularly prominent finding was that, after controlling for age, gender, spatial ability and position errors remained independent significant predictors of math ability. Greater spatial ability predicted higher math performance, whereas the number of position errors was significantly negatively related to math ability even after controlling for spatial ability. Although they only accounted for 1.9 per cent of the variance in math ability, this proportion is notable within the small amount of unexplained variance after age and gender are accounted for (e.g. 25.6%).

Previous research has examined visuospatial functioning and construction abilities (e.g., Brosnan, 1998; Caldera, *et al*., 1999; Casey, *et al*., 2008). Importantly, it has also been shown that construction play and spatial abilities are related to, and predict, mathematical achievement (Burnett, *et al*., 1979; Casey, *et al*., 1995; Geary, *et al*., 2000; Kamii, *et al*., 2004; Wolfgang, *et al*., 2003; Nath & Szücs, 2014). The current study replicated and extended these findings, showing that spatial ability, as measured by the Surface Development Test, predicted mathematical ability in the 10-14 year-olds, even after controlling for age. An important extension to this explanation of mathematical ability is the finding that construction task performance, measured by position errors, is a unique and significant predictor of mathematical ability after accounting for the effects of age and spatial ability. Findings indicated that this measure of construction play task performance predicted mathematical SAT level from ages 7-14 years. To confirm a novel contribution of construction task performance, further examination of the relationship between construction abilities and visuospatial functioning is required, with other spatial tasks such as the Block Design subtest of the WISC-IV (see also Voyer, Voyer, & Bryden, 1995), or test batteries such as the Rey-Osterreith Complex Figure test (Meyers & Meyers, 1995; Rey, 1964), and/or the Wide-Ranging Assessment of Visuo-Motor Abilities (Adams & Sheslow, 1995). If such measures were found to be related to mathematics ability in a similar fashion to construction performance, the nature of the spatial role of position errors could be identified and would also provide evidence that the construction task method could be utilised as a standardised measure of spatial abilities. It is interesting to note that than completion time, construction performance measured by position errors (fixing the correct component in the wrong place) predicts math performance independently of spatial ability. It can be argued that errors better relate to the assessment of math performance, and they may also tap into a different aspect of visuospatial functioning.

These findings show that it is possible to quantify construction play task difficulty and to design construction play kits with certain block characteristics (e.g. asymmetrical) in a controlled manner in order to progressively increase complexity and develop children's thinking. For example, a series of kits could increase the spatial complexity through increasing asymmetry, while holding other predictors of complexity at a low level. Further research in this area is required to explore the impact of such tasks and investigate the progression of children’s cognitive abilities using standardised developmental assessments. Children's construction play is one of the few predictive activities that can be reliably and validly observed in young children. Once again carefully developed construction tasks could form a construction play based screening tool for mathematical ability in order to identify students who might struggle with mathematics, enabling measures to be taken in the intervening years. The interventions could also be construction play based given the evidence that construction play can help develop children’s thinking and lay the foundations needed for later achievement in math (e.g., Kersh, Casey, Mercer Young, Spodak, & Saracho 2008; Wolfgang, Stannard, & Jones, 2003).

One of the limitations of the study was that spatial abilities were not investigated in the younger children aged 7-8 years. Initial piloting of the study found that the Surface Development Test was not appropriate for use with the younger children. Given time constraints in schools it was decided to use the test found to correlate with construction task performance in adults (the original construction tasks are also the same) and that decision has been supported by the significance of the results based on this measure.

This study has provided evidence that construction performance predicts math ability after controlling for spatial ability and that the construction task characteristics methodology developed by Richardson and colleagues can be used to quantify and systematically control the difficulty of construction tasks across childhood and adolescence. The ability to quantify construction play task difficulty and observe construction performance provides the possibility of developing construction play based screening tools or interventions to improve mathematical ability. Whilst further research needs to be undertaken on a more random sample of children, the results presented provide a sound basis for further research into the creation of construction play based interventions that can ultimately have applied educational benefits.

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Table 1. Task variable levels for each assembly.

Assembly	Components	Symmetrical Planes	Novel Assemblies	Selections
		Original Tasks		
Bed	12	1.83	3	17
Chair	5	1.8	4	8
Desk	4	0.75	2	4
L-Desk	8	1.75	6	8
Shelf	7	2	3	17
Lounger	5	0.8	4	15
Table	9	0.67	3	9
		New Tasks		
Abstract 1	5	1.80	4	10
Abstract 2	9	0.56	8	9
Abstract 3	9	2.00	2	9
Abstract 4	6	1.83	5	11
Abstract 5	5	1.80	2	10
Abstract 6	9	2.00	2	9
Abstract 7	4	1.00	1	9

Table 2. Regression of construction time (seconds) on construction characteristics of recognisable construction tasks.

	7-9 Years	10-12 Years	13-14 Years
R	.771	.748	.830
R^2	.594	.559	.688
R^2_{adj}	.510	.467	.624
R^2_{change}	.366	.287	.367
Independent variable			
Components			
β	.36 **	.36 **	.43 **
B	0.04	0.04	0.03
SE	0.01	0.01	0.01
pr	.44	.42	.55
Symmetrical Planes			
β	-.39 **	-.49 **	-.41 **
B	-0.22	-0.27	-0.13
SE	0.05	0.05	0.02
pr	-.45	-.52	-.52
Novel Assemblies			
β	.18 *	.24 **	.27 **
B	0.05	0.06	0.04
SE	0.02	0.02	0.01
pr	.25	.32	.41
Selections			
β	.43 **	.27 **	.33 **
B	0.03	0.02	0.01
SE	0.01	0.01	0.00
pr	.48	.32	.43

* $p < .05$; ** $p < .01$

Table 3. Regression of construction time (seconds) on construction characteristics of new abstract construction tasks

	7-9 Years	10-12 Years	13-14 Years
R	.712	.850	.855
R^2	.507	.723	.730
R^2_{adj}	.405	.666	.675
R^2_{change}	.303	.456	.547
Independent variable			
Components			
β	.24 **	.34 **	.38 **
B	0.05	0.07	0.07
SE	0.02	0.01	0.01
pr	.29	.50	.55
Symmetrical Planes			
β	-.38 **	-.32 **	-.36 **
B	-0.33	-0.27	-0.25
SE	0.07	0.05	0.04
pr	-.43	-.49	-.53
Novel Assemblies			
β	.41 **	.51 **	.56 **
B	0.10	0.12	0.11
SE	0.02	0.01	0.01
pr	.49	.68	.72
Selections			
β	.10	.16 **	.06
B	0.01	0.02	0.01
SE	0.01	0.01	0.01
pr	.13	.27	.10

* $p < .05$; ** $p < .01$

Table 4. Summary of the ecological correlations between predicted and actual construction times.

7-9 Years Abstract Models	0.869*
7-9 Years Original Models	0.918**
10-12 Years Abstract Models	0.954**
10-12 Years Original Models	0.863*
13-15 Years Abstract Models	0.929**
13-15 Years Original Models	0.971**

* $p < .05$; ** $p < .01$

Table 5. Pearson correlations between each age (years), gender, spatial ability, maths ability and time and position errors during construction play

	Age	Gender	SDT	Maths	Time	Position errors
Age	1	.23*	.47***	.94***	-.59***	-.50***
Gender		1	.002	.26*	.16	.07
SDT			1	.68***	-.49***	-.55***
Maths				1	-.61***	-.57***
Time					1	.61***
Position errors						1

* p < .05; *** p < .001

Table 6. Hierarchical multiple regression with math ability regressed onto age (years), spatial ability, construction task time (seconds), and task position errors.

Step	Variable	R^2	R^2 change	B	β
1	Age	.744***	.744***	2.14	.85***
	Gender			0.35	.05
2	Age	.842***	.098***	1.70	.67***
	Gender			0.725	.10
	SDT			0.14	.36***
3	Age	.849***	.007	1.62	.64***
	Gender			0.93	.12*
	SDT			0.12	.32***
	Time			-0.002	-.10
4	Age	.868***	.019**	1.67	.66***
	Gender			0.92	.12*
	SDT			0.10	.26***
	Time			0.001	.03
	Pos. errors			-0.19	-.21**

*$p < .05$; **$p < .01$; *** $p < .001$

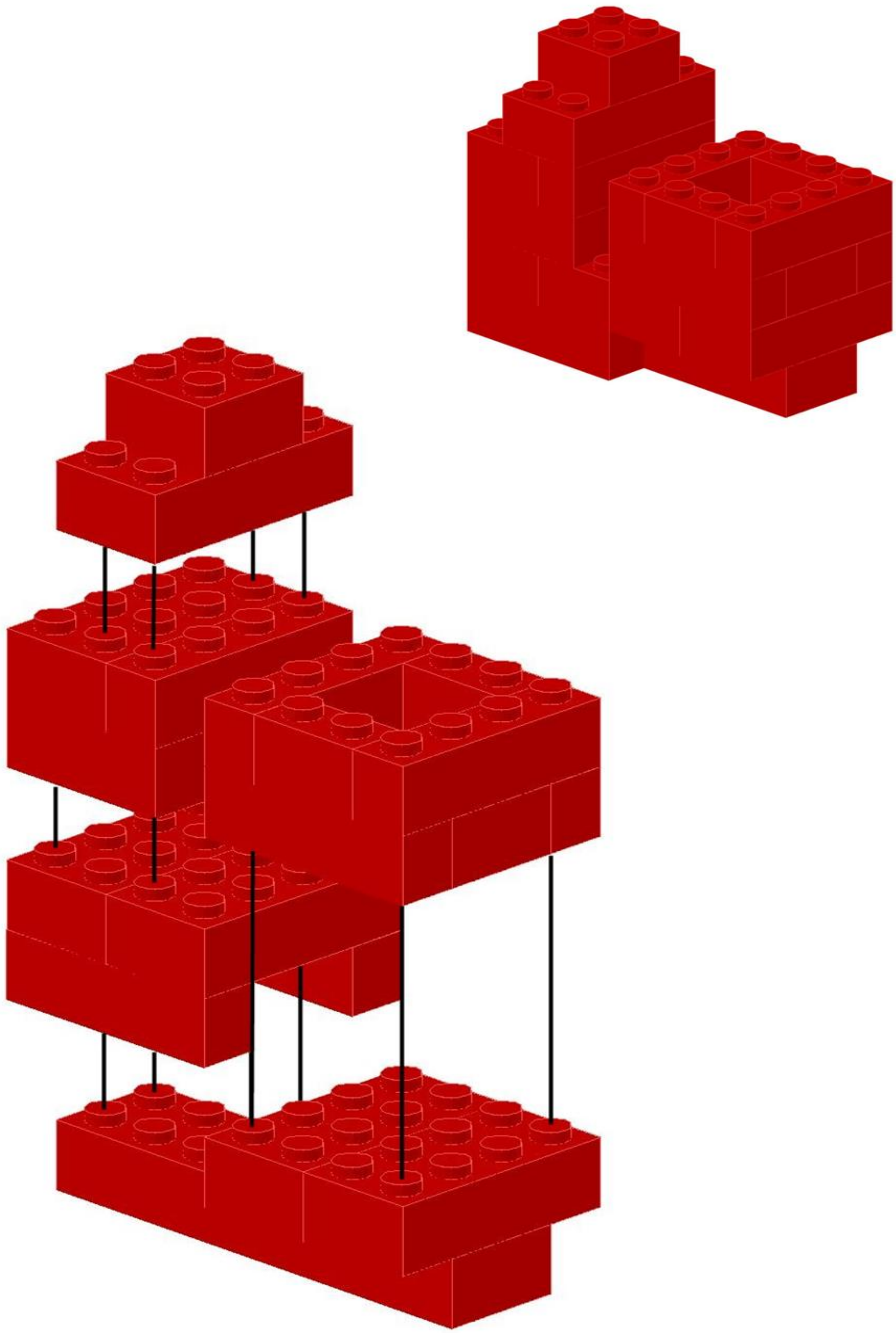

Figure 1. Exploded isometric instructions of one of the construction tasks.