# Identifying the task characteristics that predict children's construction task performance.

Miles Richardson [a], Gary Jones [b], Steve Croker [a] and Stephen L. Brown [c]

[a] University of Derby, Kedleston Road, Derby DE22 1GB, UK. M.Richardson@derby.ac.uk & S.Croker@derby.ac.uk

[b] Nottingham Trent University, Burton Street, Nottingham NG1 4BU UK. Gary.Jones@ntu.ac.uk

[c] University of Liverpool, Liverpool L69 3BX, UK. S.L.Brown@liverpool.ac.uk

Pre-print of:

Richardson, M., Jones, G., Croker, S. and Brown, S.L. (2011). Identifying the task characteristics that predict children's construction task performance. *Applied Cognitive Psychology*, 25(3), 377-385.

# Identifying the task characteristics that predict children's construction task performance.

Abstract

Construction tasks can be linked to achievement in maths and science and form part of school curricula. However, there is little foundation for their use in teaching as there are no apparent methods for assessing difficulty. This empirical research identifies four construction task characteristics that impact on cognition and influence construction task difficulty in children aged 7-8 and 10-11. Further a regression model from previous research with adults predicted children's construction task performance in the present study. The research provides a method to quantify, predict and control the complexity of construction tasks for future research and to inform teaching.

Keywords: Construction tasks; Construction Play; Cognition.

# 1. Introduction

Construction tasks involve making objects from components and are an example of a major theme of children's play and learning (Piaget, 1962; Wolfgang & Wolfgang, 1999). Although play in general has been studied extensively, the attention given to construction play has been limited (Wolfgang, Stannard & Jones, 2003). Given the ubiquity of construction and assembly tasks from infants' and children's play, through school curricula and into adulthood in tasks such as product assembly, the lack of understanding of construction and assembly ability and its development is surprising. This on its own is justification for further research, but there are further compelling reasons why this area should be investigated with children. First, play preferences for construction toys have been linked to later achievement in maths, science and possibly language development (e.g. Greenfield, 1991; Kersh, Casey, Mercer Young, Spodak and Saracho 2008; Wolfgang et al., 2003). Second, construction tasks form a part of design and technology curricula; and a greater understanding of the characteristics of construction tasks can inform curriculum development in the future. Third, once a greater understanding of norms in this area is achieved, construction tasks can provide excellent opportunities for investigating and identifying atypical development for children so that appropriate teaching interventions can be planned. Fourth, there is no apparent method for assessing and predicting assembly difficulty in children. In the current article, we use a novel methodology for empirical research into children's construction task performance to identify task characteristics that impact on cognition and influence construction task difficulty.

Construction tasks such as object assembly are paradigm examples of complex events (Zacks & Tversky, 2003) that depend upon a range of cognitive aspects, such as visuo-spatial cognition, imagery, visual search and spatial problem solving, all of which place demands on working memory (Pillay, 1997). Construction from components requires both an understanding of the components and perception of spatial relationships (Brosnan, 1998); and production of more complex structures can be related to the development of a child's capacity to represent spatial relationships mentally (Casey, Andrews, Schindler, Kersh, Samper & Copley, 2008). Given that construction tasks depend upon a range of cognitive abilities it can be predicted that assembly performance will reflect the development of cognition. For example, through development, there are distinct cognitive changes (e.g. how the task is organised) in children's block building (Casey et al., 2008). Spatial abilities, such as manipulation of mental representations, that underlie construction tasks (Clements, 1999) are based in working memory (WM) and the majority of research into the development of WM shows a steady increase in capacity from early childhood through to adolescence (e.g. Dempster, 1981). Gathercole, Pickering, Ambridge and Wearing (2004) state that from the age of 4 through to adolescence each component of working memory undergoes a linear increase in capacity, and that the basic structure of Baddeley & Hitch's (1974) working memory model is present by 6 years of age. We would, therefore, expect proficiency on assembly tasks to be related to these developments in WM.

As cognitive development will impact on children's assembly ability it is not surprising that play preferences for construction toys have also been linked to the development of visuo-spatial skills (Brosnan, 1998; Caldera, Culop, O'Brien and Truglio, 1999), which in turn have been related to later achievement in maths and science (Assel, Landry, Swank, Smith & Steelman, 2003; Burnett, Lane, & Dratt, 1979; Casey, Nuttall, Pezaris & Benbow, 1995; Casey, Nuttall, & Pezaris, 1997; Geary, Saults, Liu, & Hoard, 2000; Robinson, Abbott, Berninger, & Busse, 1996; Tracy, 1990). There is also evidence that early play with construction tasks is linked to later academic achievement. Wolfgang et al. (2003) identified a relationship between LEGO performance at preschool and mathematical achievement in high school and Kamii, Miyakawa and Kato (2004) concluded that block play encourages the development of mathematical thinking in young children. Furthermore, Kersh et al. (2008) suggest that construction using blocks provides a rich context for spatial and mathematical thinking thereby encouraging the development of maths concepts and Casey et al. (2008) suggest that given these connections the development of construction play could be an effective way of developing spatial and mathematical thinking in young children. There is also evidence that object assembly and speech production have common neurological foundations (Greenfield, 1991). Finally, the role of play, in general, is an important part of early intervention for children with developmental disabilities (Casby, 2003). Based on the evidence above, if there were a method to establish construction task difficulty at various age points, then construction could be used as part of an assessment battery in identifying weak areas of a child's abilities.

*1.1. Previous Research on Construction tasks*

Novick and Morse (2000) noted that previous research using assembly tasks has not attempted to control the complexity of the task itself – further stating that there is no apparent methodology to do so. Casey et al. (2008), based on the work of Reifel and Greenfield (1982), have rated the structural complexity of children's block constructions in terms of spatial dimensionality and hierarchical integration, but this is a more general classification of assembly types produced during free play that is not embedded in task characteristics that can vary within any one type of assembly (e.g., assemblies classified as 3D horizontal enclosures can vary in complexity). However, a method based on task characteristics has recently been validated in adults. Research examining the assembly performance of adults has identified physical characteristics of constructions that relate to cognitive function and assembly performance. This allows the difficulty of a construction to be quantified and predicted (Author, Author & Author, 2004; Author, Author, Author & Author, 2006). These represent the first attempts that we know of to provide evaluations of construction task difficulty and control them in an experimental setting.

In the experiments reported by Author et al. (2006), construction task variables hypothesised to impact on cognition (which are detailed below) were systematically varied in a balanced fractional factorial and orthogonal design. Adult participants were observed carrying out a range of construction tasks that varied in their construction task variable levels. A clear relationship between the construction task variables and assembly complexity was found and a regression model developed. This model successfully predicted the difficulty of a variety of new construction tasks built by different participants using different materials (with ecological correlations up to r=0.99). Further, the theoretical basis of the construction task variables and regression analysis allowed the most important construction task variables to be identified and placed in a cognitive context. This research provides a theoretical basis (cognitive load), presented below, and a methodology which is proven with adults, but untested with children.

*1.2. Theoretical Basis of Construction Task Variables*

The construction task variables hypothesised by Author et al. (2004, 2006) were derived from a task analysis that identified four fundamental sub-operations of a typical assembly procedure. These were *Selection of the component(s)* required for the next assembly procedure; *orientation or rotation of component(s)* to allow positioning; *positioning of component(s)* to allow fastening; *fastening of component(s)* to allow assembly. The sub-operations identified were mapped on to physical characteristics of assemblies that were hypothesized to impact on cognition and therefore affect assembly complexity. The construction task variables (described below) were found to be significant predictors of assembly task complexity and performance in adults by Author et al. These task characteristics can therefore be hypothesised to predict children's task performance as children have the same fundamental cognitive structures as adults, with limited processing capacity (e.g WM). The construction task variable definitions and justification will now be introduced.

*1.2.1. Selections* (S). The total number of components available to select from at the start of the assembly task. Selection of components for the next assembly procedure is affected by the number of components to choose from. The number of elements to be searched has a dominant effect on search time (Drury & Clement, 1978), so the number of components available for selection impacts on cognition and assembly complexity. According to Gerhardstein & Rovee-Collier (2002), there are no qualitative differences in visual search performance between infants, very young children and adults. Development of visual search, therefore, seems to be synonymous with an increase in processing speed. It can be predicted that the underlying differences in information processing will lead to differences between children and adults.

*1.2.2. Symmetrical Planes* (SP). The mean number of symmetrical planes per component measured in three planes, X, Y and Z. Orientation involves three-dimensional mental representations that require time, effort and processing resources (Cooper, 1988). Such spatial orientation and manipulation is sensitive to the complexity or amount of information processed simultaneously (Denis, 1991). However, the orientation of the component to allow positioning is affected by the characteristics of the component, (e.g. a symmetrical component can be correctly placed in more than one orientation). Therefore, decisions relating to orientation are related to the number of symmetrical planes of the component. With a higher level of symmetrical planes fewer rotations are required until the correct orientation is found. Brosnan (1998) reported a correlation between children's ability to replicate a complex Lego structure and their mental rotation task performance. Such spatial abilities are reliant on WM, both of which develop throughout childhood (Clements and Battista ,1992; Van Hiele, 1986; Dempster, 1981). It is argued assembly performance is highly dependent on the level of component symmetry, which itself is related to spatial skills which develop throughout childhood, therefore it can be hypothesised that this variable will be susceptible to age affects and of greater importance in children than adults.

*1.2.3. Components* (C). Number of components (excluding fastening devices such as screws). The number of components impacts on assembly complexity owing to the simple relationship with the amount of information being processed in WM (Kalyuga, Chandler & Sweller, 1998). As the capacity of WM increases throughout childhood, the number of components should have a more marked effect on task performance in children than in adults.

*1.2.4. Novel Assemblies* (NA). The number of unique assembly procedures in a construction. If an assembly procedure is repeated during an assembly with the same components, its sub-operations will have been successfully performed before and will exist in the users WM for a repeat procedure. Therefore the demands on processing resources are reduced (Cooper, 1988). As above, given the development of WM throughout childhood, the variety of components and therefore number of unique assembly procedures should have a more marked effect on task performance in children.

### *1.3. Aim and Hypotheses*

In summary there are compelling reasons to investigate construction play in children given the paucity of research in this area. A fundamental requirement to allow wider investigation of construction tasks is a sound methodology. In the following experiments the four construction task characteristics found to be significant in adults by Author et al. (2006) are systematically varied in a series of construction tasks while holding the mode of task presentation (diagrammatic instructions) constant. The primary aims of the first two studies presented here are to demonstrate that the methods used by Author et al. (2006) can be applied to children, and that the construction task characteristics that predict adult assembly performance predict assembly complexity in children (aged 7-8 and 10-11). The research also aims to consider age effects through direct comparisons. The analysis of the impact of these characteristics at different ages also gives an insight into the development of construction ability in children. Based on the literature presented above, it is hypothesised that the four task characteristics will predict children's task performance and that the relationship will be susceptible to age affects.

## 2. Exeriment 1

### *2.1. Method*

The research methodology used by Author et al. (2006) was repeated. The construction task variables, derived from cognitive theory and defined above, were varied in seven balanced, fractional factorial and orthogonal assembly tasks while holding the mode of task presentation (instructions showing a standard exploded isometric view and a final target diagram) constant. Whilst the importance of the instructions is acknowledged, it is the characteristics of an assembly task that fundamentally define an assembly's complexity. Participants in two age groups constructed all seven objects in a repeated measures design, allowing the relationship between the construction task variables and children's assembly performance to be studied.

The time taken to complete each assembly is measured. It is proposed that time based performance differences are related to complexity and the qualitative state of the task (Stankov, 2000), and to basic elements of the cognitive system such as working memory owing to limited capacity and short duration (Arend et al., 2003).

#### *2.1.1. Participants*

There were two age groups. 8 participants aged 7 and 8 years and 8 children aged 10 and 11 years. All were pupils at a primary school in Derbyshire, United Kingdom. There were an equal number of boys and girls in each group. The participants were selected with no set criteria by their teacher to take part in the study. The repeated measures design produced 56 observations per age group (8 participants x 7 assembly tasks) which exceeds the number required (Green, 1991) to repeat the analysis used in the previous published research of Author et al. (2004, 2006).

*2.1.2. Materials*

The construction task variables hypothesized to have an impact on cognition and therefore complexity and performance were manipulated in a series of constructions tasks. The tasks used were seven LEGO assemblies based on real world objects with between four and twelve components and identical to those used by Author et al. (2006). Commercial real world assemblies were not used because their task variable levels tend to strongly correlate with each other (Author et al., 2004). These assembly tasks were designed to provide sufficient independent variability to disambiguate the separate effects of the variables, and to control collinearity in the regression analysis. To ensure an orthogonal design the assemblies were modified based on an iterative process as follows; calculation of the four construction task variable levels for each assembly; analysis of correlation between task variables; and modification of assemblies ensuring a range of task variable levels (High and Low based on the mean) and reduction of any high correlations. Table 1 shows the task variable levels that were used to design each assembly. For example, the chair (see Figure 1) contained: A low number of component parts, a high level of symmetrical planes, a variety of components to create a high number of novel assemblies, and a low level of selections. All assemblies used one colour only. Two more practice assemblies were also used. Single step exploded isometric instructions (see Figure 1) and target diagrams of the completed assemblies were used as paper based instructions. The use of paper based two-dimensional exploded isometric instructions mirrors what is found in typical assembly tasks.

------------------------------

Insert Table 1 about here

------------------------------

------------------------------

Insert Figure 1 about here

------------------------------

*2.1.3. Procedure*

The study was administered on a one-to-one basis in a quiet area of the school (the school library). Each child was briefed with an explanation of the task. They were also informed that the experimenter would present the pieces to them when they were ready to begin and that the stop watch would then be started to record the time taken to build the object that they could see in the picture. Participants were also instructed to say ‘stop’ out loud when they had finished building the object so that the experimenter could stop the timing and record the time taken. It was also emphasised to them that they not to rush as we were not interested in how quickly they made the object, but measuring which objects were harder to make than others. Participants were then told that they were allowed to stop the experiment at any point if they wanted to. After verbal confirmation that the participant understood everything that they were told they were then presented with two short practice trials. In trial one the experimenter demonstrated the two possible ways to aid the construction by using the step-by-step guide in the main picture or the completed assembly diagram in the small picture on the top right hand corner of the same page. The experimenter explained that sometimes it may be beneficial to use the combination of pictures to see how the object needed to be built at each stage and also what it should look like at the end. At this stage the participants were also informed that some of the sets had too many pieces and were advised to follow the instructions carefully if they needed help finding which piece was required.  Participants were then given the opportunity to have a practice run with the second practice trial.  After successful completion of the practice trials participants were then asked again if they understood all the information that they were just given and if they were still happy to proceed with the task.  At this point participants were given the opportunity to ask any questions or clarify any of the instructions.  The experimenter also explained that they would be unable to help or answer any questions whilst they were building the objects, but if necessary they could stop and withdraw from the experiment. The order of presentation of the seven construction tasks was counterbalanced.

### *2.2. Results*

#### *2.2..1 Coding*

In previous studies using nut and bolt fastenings, a coding scheme to remove the variability in the total assembly time due to the time spent on fastening procedures was required. The time remaining ('thinking time') reflected the time participants had spent viewing the instructions and deciding how to assemble the object. Push-to-fit fastening used here means that fastening times for assemblies are low, indeed it is difficult to identify a time for fastening because fastening occurs so quickly. The separation of fastening and thinking times was therefore not necessary, with total assembly time used as a measure of thinking time. Author et al. (2006) analysed timings from a sample of LEGO assemblies and found coded thinking time had a significant strong positive correlation with the total assembly time ($r(5)=0.976$, $p<0.01$).

#### *2.2.2. Relationship of Construction Task Variables to Assembly Time*

Assembly time was transformed for each assembly as it was skewed towards zero, DV = LOG(Assembly Time). To examine the relationship between thinking time and the assembly task variables, multiple regression analysis was used for each age group.

##### *2.2.2.1 Age 7-8 years old*

All 56 observations of assembly time for the 7 assemblies were included in the analysis. As there was multiple data for each participant, dummy variables to identify each participant were entered in the first block in order to control for variability due to individual differences (Pedhazur, 1982). The four construction task variables (Components, Symmetrical Planes, Novel Assemblies and Selections) were entered in the second block. The between participant dummy variables in model 1 gave $R$=0.43 and $R^{2adj}$=0.07. The second model including the four construction task variables gave $R$=0.83 and $R^{2adj}$=0.61, $F(11,44)$=8.705, $p$<.001, with the $R^2$ Change figure suggesting that 50% of the variance in assembly time was related to some combination of the construction task variables. All four of the entered task variables were significant predictors of assembly time at the $p$=0.05 level. Standardized regression coefficients for each task variable suggest that an increase in assembly time was associated with an increased number of Components (0.348, $t(52) = 3.54$, $p$<.01), a higher number of Novel Assemblies (0.428, $t(52) = 4.67$, $p$<.001), a reduced level of Symmetrical Planes (-0.551, $t(52) = -5.36$, $p$<.001) and an increased number of Selections (0.492, $t(52) = 4.74$, $p$<.001).

*2.2.2.2. Age 10-11 years old*

All 56 observations of assembly time for the 7 assemblies were included and the analysis described above was repeated. The between participant dummy variables in model 1 gave $R$=0.50 and $R^{2adj}$=0.14. The second model including the four construction task variables gave $R$=0.73 and $R^{2adj}$=0.42, $F(11,44)$=4.547, $p$<.001, with the $R^2$ Change figure suggesting that 29% of the variance in assembly time was related to some combination of the construction task variables. All four of the entered task variables were significant predictors of assembly time at the $p$=0.05 level. Standardized regression coefficients for each task variable suggest that an increase in assembly time was associated with an increased number of Components (0.345, $t(52) = 2.88$, $p$<.01), a higher number of Novel Assemblies (0.252, $t$(52)

= 2.32, $p<.05$), a reduced level of Symmetrical Planes (-0.381, $t(52) = -3.04$, $p<.01$) and an increased number of Selections (0.324, $t(52) = 2.565$, $p<.05$).

*2.2.3. Prediction of Thinking Time*

The task variable scores for each of the 7 assemblies were entered into the regression equation produced by Author et al. (2006) to produce predicted assembly times. This regression equation was based on data collected from 12 adults building 16 abstract Meccano assemblies. The predicted assembly times were compared to the actual mean assembly times for each of the 7 assemblies for the 10-11 year olds (see Table 2 and Figure 2) showing a strong ecological correlation ($r(5) = 0.914$, $p<.01$). The predicted assembly times were then compared to the actual mean assembly times for each of the 7 assemblies for the 7-8 year olds (see Table 2 and Figure 3), again showing a strong ecological correlation ($r(5) = 0.814$, $p<.05$).

------------------------------

Insert Table 2 about here

------------------------------

------------------------------

Insert Figure 2 about here

------------------------------

------------------------------

Insert Figure 3 about here

------------------------------

## 3. Experiment 2

### *3.1. Method*

*3.1.1. Participants*

12 females and 8 males, age range 18 to 52, from a variety of backgrounds.

*3.1.2. Materials*

The materials were the same as those used in experiment 1.

*3.1.3. Procedure*

The experiment took place in a room containing a PC, monitor and a 30 inch square assembly area in front of the PC. Participants were seated and told that the PC would be used to present the instructions for the practice assemblies and 7 further assemblies, and their task was to complete each assembly. Participants were informed that they should follow the on screen instructions presented on the PC monitor and that sometimes more components than needed to complete the assembly would be provided. Finally, they were told that before each assembly the PC would beep and the investigator would arrive with the relevant box of components and remove any completed assembly. Participants would then press the space bar on the PC keyboard to reveal the instructions and begin the assembly, pressing the space bar again once the assembly was complete. The instructions for the 7 assemblies were presented in a random order.

*3.2. Results*

*3.2.1. Relationship of Construction Task Variables to Assembly Time*

All 140 observations of assembly time for the 7 assemblies were included and the analysis described previously was repeated. The between participant dummy variables in model 1 gave $R$=0.57 and $R^{2adj}$=0.22. The second model including the four construction task variables gave $R$=0.87 and $R^{2adj}$=0.71, $F(23,116)=16.109$, $p<.001$, with the $R^2$ Change figure suggesting that 44% of the variance in assembly time was related to some combination of the construction task variables. All four of the entered task variables were significant predictors of assembly time at the $p$=.05 level. Standardized regression coefficients for each task variable suggest that an increase in assembly time was associated with an increased number of Components (0.405, $t(116) = 7.68$, $p<.001$), a higher number of Novel Assemblies (0.301, *t*(116) = 6.05, *p*<.001), a reduced level of Symmetrical Planes (-0.459, *t*(116) = -8.33, *p*<.001) and an increased number of Selections (0.431, *t*(116) = 7.75, *p*<.001). Assembly times for each model are provided in Table 3.

-----------------------------

Insert Table 3 about here

-----------------------------

*3.2.2. Comparison across ages*

The multiple regression results from the three studies above reveal that the four task variables were significant at all age points. That is, task difficulty is associated with increases in the number of components, novel assemblies, and selections, and a decrease in the number of symmetrical planes. However, what is more important is the predictive quality of each of these task variables at each age.

A hierarchical regression analysis was conducted to investigate the interaction between age and task variables in predicting assembly time. Variables were entered in three sequential blocks, dummy participant identity variables to control between subject effects, main effects of age category and task assembly variables and, last, interactions between age and task assembly variables.

To create a single variable representing cumulative between participant differences, assembly time was regressed onto all between participant variables, and predicted values saved as scores. This variable was entered as block 1 to control between participant differences. The age category variable (coded adult=1, age 10-11=2 and age 7-8=3) and task variables were entered as block 2. Four interaction terms were computed by centring the task variables and multiplying them by age category. These were entered as block 3. A significant change in $R^2$ after the entry of each block signifies that the block adds to explained variance, controlling variables entered at previous steps. This provides a single conservative significance test of all interactions (Aiken & West, 1991). The block change in $R^2$ is preferred to assessment of standardised betas of individual predictors, which can be unstable due to multicollinearity (Cohen & Cohen, 1983).

The overall equation was significant ($R^{2adj}$=.77, $F$ (4,184) = 139.53, $p$<.01). The between subjects variable explained 38.6% of variance in assembly time ($p$<.01). The entry of age category and task assembly main effect variables for symptoms showed a significant $R^2$ increase of 33.4%. Entry of block 3 representing the interaction variables showed a significant $R^2$ increase of 1.7% ($p$<.05).

Follow-up individual analyses were conducted to establish which variables contributed to the interactions. Z Tests were used to compare the unstandardised regression coefficients from the three age groups (Paternoster, Brame, Mazerolle, & Piquero, 1998). This method requires regressions performed in separate groups and variables in the regression model in each group that are the same. It is a fairly conservative method and follows on from more extensive work by Clogg, Petkova and Haritou (1995). Two construction task variables were found to have significant differences ($p$<.05) between the 7-8 year olds and adults: Symmetrical Planes (Z=-2.071) and Novel Assemblies (Z=2.154). Components (Z=0.574) and Selections (Z=1.707) were not significant. No other comparisons were significant. The 10-11 year olds unstandardised regression coefficients were similar to those of adults (see Table 4 and Figure 4), suggesting that by age 10-11 the task variables are having a similar affect on children's performance as they do on adult performance, showing a rapid development over the intervening 3 years. However, the difference with 7-8 years olds was not significant owing to a larger standard error.

------------------------------

Insert Table 4 about here

------------------------------

------------------------------

Insert Figure 4 about here

------------------------------

Table 4 and Figure 4 show how the impact of the construction task variables (shown by unstandardised betas) varies between age groups; dropping rapidly from age 7-8 to age 10-11 and level from age 10-11 to adult. The novel assemblies and symmetrical planes variables in particular have a greater affect on construction time at the youngest age group.

## 4. Discussion

It is clear from the results that the primary aim of the research has been met. The methodology used by Author et al. (2006) can be successfully applied to investigate construction tasks in children. This alone is notable as it provides a method to evaluate and control the complexity of assembly tasks in further research. There are though, further findings of note. The regression model derived from abstract Meccano model performance by adults predicts children's Lego building performance very well. Finally, the four construction task characteristics that predict assembly performance in adults have been found to relate to assembly performance in 7-8 and 10-11 year olds. The results across the three age groups are convincingly consistent, but it can also be seen that age differentially relates to the construction characteristics. Notable differences were found in the impact of the construction task variables on the performance of children aged 7-8. The impact on children aged 10-11 was very similar to the impact on adults. As one may expect, adult performance was quicker overall, indicating the need to identify other variables that impact on children's construction task performance.

The four task characteristics were hypothesised to predict children's task performance based on literature suggesting that children have the same fundamental cognitive structures as adults, albeit with limited processing capacity. The results of the regression analysis clearly support this. Components, Novel Assemblies, Symmetrical Planes and Selections were significant predictors of assembly difficulty at both age points and, as expected, in adults. Furthermore, the inclusion of the adult study reveals a developmental trajectory in construction ability as well as demonstrating the robustness of the task characteristics. The interaction between age and task variables was shown to be significant by moderated regression analysis. Further analysis of beta values across age groups confirmed this finding, with those task characteristics arguably most closely linked to assembly complexity and cognitive load showing a significant interaction with age; Novel Assemblies and Symmetrical Planes.

The Symmetrical Planes task characteristic was argued to relate to spatial abilities reliant on WM, both of which develop through childhood leading to the hypothesis that this task characteristic would be of greater importance in children than adults. As predicted, the regression coefficient was noticeably higher at the youngest age point and the Z-tests revealed a significant difference in the relationship between Symmetrical Planes and performance between children aged 7-8 and adults. That is, any significant increase or decrease in the level of Symmetrical Planes has a greater impact on the assembly performance of 7-8 year olds than adults. By the age of 10-11 the impact of symmetry on performance is similar to that seen in adults.

Similarly, it was argued that the Novel Assemblies task characteristic was also related to WM capacity and its development throughout childhood, leading to the prediction that the number of unique assembly procedures would have a more marked effect on task performance in children. Once again the regression coefficient was noticeably higher at the youngest age point and the Z-tests revealed a significant difference in this relationship between Novel Assemblies and performance between children aged 7-8 and adults. By the age of 10-11 the impact of component variety (the source of Novel Assemblies) on performance is similar to that seen in adults.

The Selections task characteristic was derived from the visual search literature and was found to predict task performance in children in both age groups. It was also predicted that underlying differences in information processing would lead to differences between children and adults. The Z-tests did not reveal a significant difference in the strength of the relationship between Selections and performance between children and adults.

Finally, the Components task characteristic was again related to the demand on WM and a similar prediction was made that the number of components should have a more marked effect on task performance in children than in adults. This was not supported. However, this lack of difference across age groups provides the first evidence to support an alternative explanation that although a significant predictor of assembly performance, this result is not related to the impact of the number of components on cognition, but the common-sense notion that assemblies with more components take longer to do. Therefore, we can conclude that it is the nature of the components, their symmetry and variety, rather than pure quantity that impact on cognition and assembly complexity in children and adults, to a level above more simple measures of information load such as the number of components – which do relate to cognition, but in visual search terms.

The impact of the number of components should not be ignored though. The significance of this factor, and inclusion in a regression model, allows more accurate prediction of assembly performance and complexity. It is the accurate prediction of assembly performance and complexity and the understanding of the important task characteristics that are key to further research and application of findings in this area. The results of the studies above, together with the findings from Author et al. (2006) which predicted children's performance well, show that the approach of using assembly task characteristics to study assembly difficulty is reliable and that the task variables identified are valid. It is also important to note that Author et al. found a convincing level of consistency in results when using different assemblies, made using different construction materials and different task variable combinations. This suggests that the findings presented here are not limited to LEGO assemblies, but can be applied to a broader range of construction tasks.

The methodology and results from this and previous work (Author et al., 2006) inform future empirical study involving construction tasks and children. The control of variables is fundamental to any experimental work and previously there has been no method for achieving this (Novick & Morse, 2000). The four task characteristics can be used to design controlled construction tasks or quantify and predict the difficulty of existing assemblies, or assembly steps, as defined by assembly instructions. With further data collection the methodology can be used to prepare age-appropriate construction tasks for various age points. Furthermore, it may be possible to combine the present task characteristics approach with ratings of spatial dimensionality and hierarchical integration used by Casey et al. (2008). The cognitive basis of the task variables also allows controlled construction tasks to be used in wider research with children. For example, materials could be developed for research related to spatial WM where component symmetry could be varied while holding other construction task characteristics constant.

Given the link between construction task use in children and later achievement in maths, science and possibly language development, additional research into the normative development of construction task abilities (with controlled materials) would allow construction play based assessment of atypical ability and inform the development of early intervention strategies that allow bespoke teaching and learning plans. Further, the ability to quantify and predict the difficulty of a given construction task for children of different ages informs curriculum design such that age and ability appropriate construction based exercises can be created. Therefore, in the longer term, the research strand opened up by this study could benefit those involved in education from curriculum designers to teachers and to children, who can benefit from a well designed curriculum.

## 5. References

Aiken, L. S., & West, S. G. (1991). *Multiple Regression: Testing and interpreting interactions*. Newbury Park, CA: Sage.

Arend, I., Colom, R., Botella, J., Contreras, M., Rubio, V. & Santacreu, J. (2003). Quantifying cognitive complexity: evidence from a reasoning task. *Personality and Individual Differences*, 35, 659 – 669.

Assel, M. A., Landry, S. H., Swank, P., Smith, K. E., & Steelman, L. M. (2003). Precursors to mathematical skills: Examining the roles of visual-spatial skills, executive processes, and parenting factors. *Applied Developmental Science,* 7, 27-38.

Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory Vol. 8* (pp. 47-89). New York: Academic Press.

Brosnan, M. J. (1998). Spatial ability in children's play with Lego blocks. *Perceptual and Motor Skills*, 87, pp. 19-28.

Burnett, S. A., Lane, D. L., & Dratt, L. M. (1979). Spatial visualization and sex differences in quantitative ability. *Intelligence,* 3, 345–354.

Caldera, Y. M., Culp, A. M., O'Brien, M., Truglio, R. T., Alvarez, M. and Huston, A. C. (1999) Children's play preferences, construction play with blocks, and visual-spatial skills: Are they related?. *International Journal of Behavioral Development*, 23, 855-872.

Casby, M. W. (2003), The development of play in infants, toddlers and young children. *Communication Disorders Quarterly*, 24, 163-174.

Casey, B.M., Andrews, N., Schindler, H., Kersh, J.E., Samper, A. and Copley, J. (2008). The Development of Spatial Skills Through Interventions Involving Block Building Activities. *Cognition and Instruction*, 26, 269 – 309.

Casey, M. B., Nuttall, R. L., & Pezaris, E. (1997). Mediators of gender differences in mathematics college entrance test scores: A comparison of spatial skills with internalized beliefs and anxieties. *Developmental Psychology,* 33, 669–680.

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, 31, 697-705.

Clements, D. H. (1999). Geometric and spatial thinking in young children. In J. V. Copley (Ed.), *Mathematics in the early years* (pp. 66–79). Reston, VA: National Council of Teachers of Mathematics.

Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 420-464). New York: Macmillan.

Clogg, C.C., Petkova, E.  and Haritou, A. (1995). Statistical methods for comparing regression coefficients between models. *American Journal of Sociology*, 100, 1261-1293.

Cohen, J., & Cohen, P. (1983). *Applied multiple regression/correlation analysis for the behavioral sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Cooper, L.A. (1988). The role of spatial representations in complex problems solving. In S. Schiffer & S. Steele (Eds), *Cognition and Representation* (pp. 53-86). Boulder, Colorado, Westview Press.

Dempster, F. N. (1981). Memory Span - Sources of Individual and Developmental Differences. *Psychological Bulletin*, 89, 63-100.

Denis, M. (1991). Imagery and Thinking. In C. Cornoldi & M. A. McDaniel (Eds), *Imagery and Cognition* (pp. 103-131). New York: Springer-Verlag.

Drury, C.G., & Clement, M.R. (1978). The effect of area, density, and number of background characters on visual search. *Human Factors*, 20, 597–602.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, 40, 177-190.

Geary, D. C., Saults, S. J., Liu, F.,&Hoard, M. K. (2000). Sex differences in spatial cognition, computational fluency, and arithmetical reasoning. *Journal of Experimental Child Psychology*, 77, 337–353.

Gerhardstein, P. & Rovee-Collier, C. (2002). The Development of Visual Search in Infants and Very Young Children. *Journal of Experimental Child Psychology*, 81, 194–215.

Green, S. B. (1991). How many subjects does it take to do a regression analysis? *Multivariate Behavioural Research*, 26, 499-510.

Greenfield, P. M. (1991) Language, tools, and brain: The ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences*, 14, 531-551.

Kamii, C., Miyakawa, Y. and Kato, Y. (2004). The development of logico-mathematical knowledge in a block-building activity at ages 1-4. *Journal of Research in Childhood Education*, 19, 44-57.

Kersh, J., Casey, B. and Mercer Young, J. Spodak, B. and Saracho, O. (eds) (2008) Research on spatial skills and block building in girls and boys: The relationship to later mathematics learning. *Contemporary perspectives on mathematics in early childhood education* (pp. 233-253). Information Age Publishing , Charlotte, NC.

Novick, L.R. & Morse, D.L. (2000). Folding a fish, making a mushroom: The role of diagrams in executing assembly procedures. *Memory & Cognition*, 28, 1242-1256.

Paternoster, R., Brame, R., Mazerolle, P., & Piquero, A. (1998). Using the Correct Statistical Test for the Equality of Regression Coefficients. *Criminology*, 36, 859-866

Pedhazur, E.J. (1982). *Multiple regression in behavioral research* (2nd ed.). New York, NY: CBS College Publishing.

Piaget, J. (1962). *Play, dreams and imitation*. New York: Norton

Pillay, H.K. (1997). Cognitive load and assembly tasks: effect of instructional formats on learning assembly procedures. *Educational Psychology*, 17, 285-299.

Reifel, S., & Greenfield, P. M. (1982). Structural development in a symbolic medium: The representational use of block constructions. In G. Forman (Ed.), *Action and thought: From sensorimotor schemes to symbolic operations* (pp. 203–233). New York: Academic Press.

Robinson, N. M., Abbott, R. D., Berninger, V. W., & Busse, J. (1996). The structure of abilities in math-precocious young children: Gender similarities and differences. *Journal of Educational Psychology*, 88, 341–352.

Stankov, L. (2000). Complexity, metacognition and fluid intelligence. *Intelligence*, 28, 121–143.

Tracy, D. M. (1990). Toy-Playing Behavior, Sex-Role Orientation, Spatial Ability, and Science Achievement. *Journal of Research in Science Teaching*, 27, 637-649.

Van Hiele, P. M. (1986). *Structure and insight*. Orlando, FL: Academic Press.

Wolfgang, C. H., & Wolfgang, M. E. (1999). *School for Young Children: Developmentally Appropriate Practices*. Boston, MA: Allyn and Bacon.

Wolfgang, C. H, Stannard, L. L., & Jones, I. (2003). Advanced constructional play with LEGOs among preschoolers as a predictor of later school achievement in mathematics. *Early Child Development and Care*, 173, 467-475.

Zacks, J.M. & Tversky, B. (2003). Structuring Information Interfaces For Procedural Learning. *Journal of Experimental Psychology: Applied*, 9, 88-100.

**Figure 1.** Exploded isometric instructions of one of the assembly tasks.

**Figure 2**. Predicted mean assembly times versus actual mean assembly times for children aged 10-11.

**Figure 3.** Predicted mean assembly times versus actual mean assembly times for children aged 7-8.

**Figure 4.** Comparing across age groups: Chart showing the unstandardised betas for each construction task variable and total assembly time for each age group.

**Table 1**. Task variable levels for each assembly.

| Assembly | Components | Symmetrical Planes | Novel Assemblies | Selections |
|---|---|---|---|---|
| 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 |
| Mean | 7.14 | 1.37 | 3.57 | 11.14 |

**Table 2.** Predicted and actual mean assembly times in seconds by model.

| | Assembly | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Predicted | 141.9 | 64.6 | 49.7 | 91.0 | 107.9 | 136.6 | 103.7 |
| Actual Year 6 | 134.9 | 39.9 | 61.5 | 96.8 | 88.6 | 118.8 | 85.3 |
| SD | 71.2 | 14.8 | 30.8 | 31.4 | 84.1 | 64.1 | 40.0 |
| Actual Year 3 | 199.1 | 92.0 | 60.1 | 169.4 | 115.1 | 266.6 | 236.0 |
| SD | 81.1 | 120.4 | 31.7 | 80.3 | 52.9 | 192.8 | 204.6 |

**Table 3.** Total and mean assembly time in seconds by model.

| | Assembly | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Total |
| Adults | 93.8 | 43.1 | 39.8 | 71.9 | 62.8 | 90.1 | 87.9 | 489.4 |
| SD | 31.1 | 27.4 | 18.7 | 26.8 | 25.7 | 38.9 | 34.5 | |

**Table 4.** Summary of regression results from experiments 1, 2 and 3.

| | | Age 7-8 | Age 10-11 | Adults |
|---|---|---|---|---|
| R | | 0.83 | 0.73 | 0.87 |
| $R^2$ | | 0.69 | 0.53 | 0.76 |
| $R^{2Adj}$ | | 0.61 | 0.49 | 0.71 |
| $R^{2Change}$ | | 0.50 | 0.29 | 0.44 |
| Independent Variable | | | | |
| Components | B | 0.348* | 0.345* | 0.405* |
| | b | 0.044 | 0.036 | 0.036 |
| | se | 0.013 | 0.013 | 0.005 |
| Novel Assemblies | B | 0.428* | 0.252* | 0.301* |
| | b | 0.119 | 0.058 | 0.059 |
| | se | 0.026 | 0.026 | 0.010 |
| Symmetrical Planes | B | -0.551* | -0.381* | -0.459* |
| | b | -0.328 | -0.188 | -0.193 |
| | se | 0.061 | 0.062 | 0.023 |
| Selections | B | 0.492* | 0.324* | 0.431* |
| | b | 0.034 | 0.019 | 0.021 |
| | se | 0.007 | 0.007 | 0.003 |

**Note**. * denotes significance of independent variable at the 0.05 level.

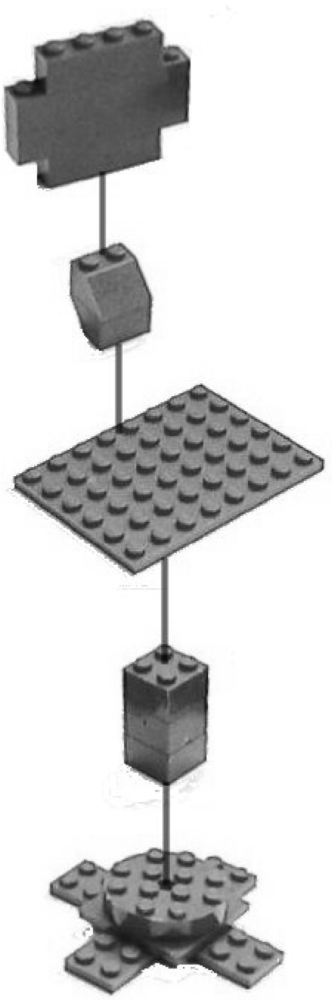

**Figure 1.** Exploded isometric instructions of one of the assembly tasks.

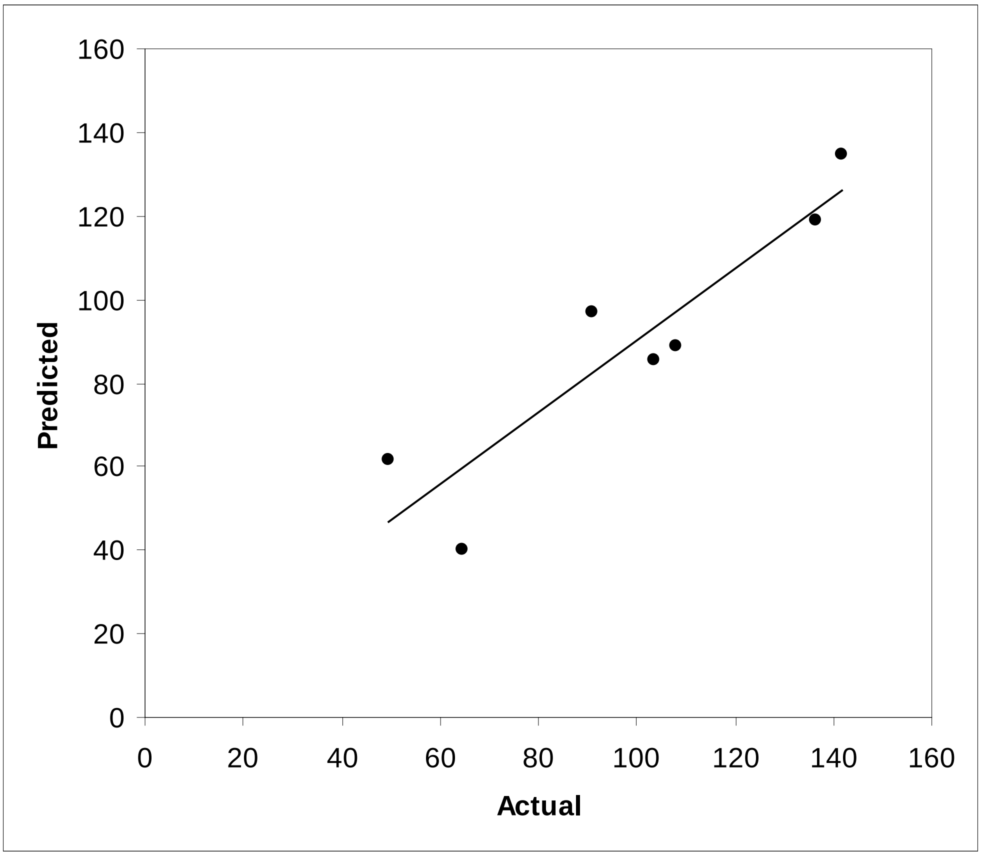


**Figure 2**. Predicted mean assembly times versus actual mean assembly times for children aged 10-11.

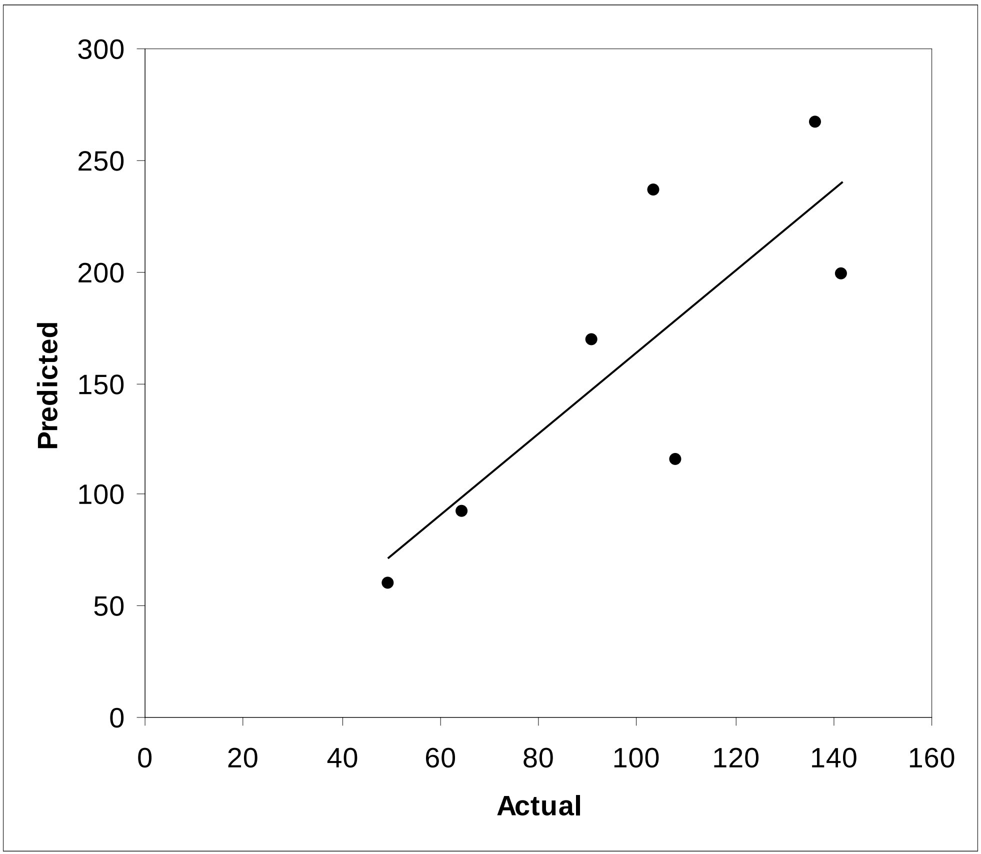


**Figure 3.** Predicted mean assembly times versus actual mean assembly times for children aged 7-8.

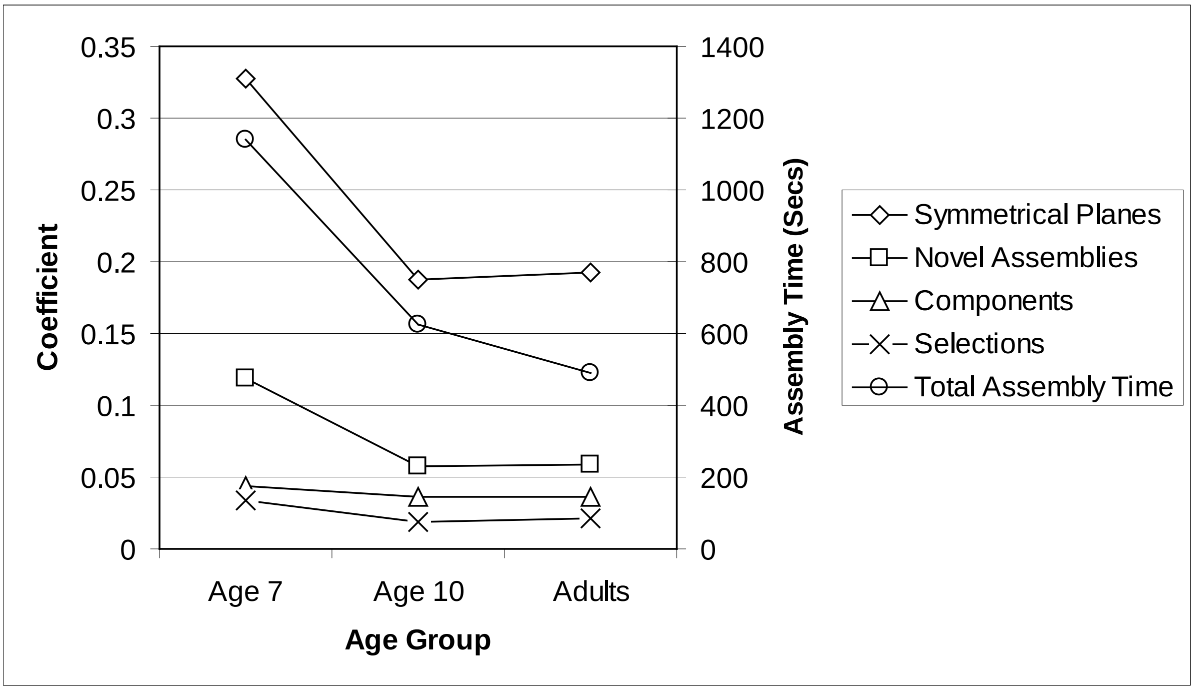


**Figure 4.** Comparing across age groups: Chart showing the unstandardised betas for each construction task variable and total assembly time for each age group.