REVIEW OF LITERATURE

Children with Learning Disabilities have stirred curiosity among the psychologists. Wide variety of research has been carried out to understand the basic nature, possible reasons behind its occurrence and its correlates. In order to gain insight into earlier researches a comprehensive review of literature was conducted in the following areas:

a) Working Memory and Mathematical Ability
b) Working Memory and Achievement
c) PASS Cognitive Processes and Mathematical Ability
d) PASS Cognitive Processes and Achievement
e) Intelligence and Working Memory

(a) Working Memory and Mathematical Ability

Working Memory is an important factor in understanding individual differences in mathematical ability among children. Research, on the role of working memory in mathematics, exist mainly on studies of children with mathematical disabilities indicating that deficits in mathematics are linked to poor working memory (Geary et al., 2000). The relations between working memory and various measures of mathematical skill have been studied extensively. Studies have shown that working memory is a strong predictor of mathematical skills across time, even when controlling for IQ, and that children with difficulties in mathematics score lower on measures of working memory. Yet, findings are inconsistent with regard to which components of working memory can predict mathematical performance, and which cannot. This is possibly a result of the complexity and variety of the tasks employed to use working memory and the range of aspects that comprise the working memory model.
Studies that test whether growth in different components of working memory and executive processes differentially predict growth in or level of skill in different mathematical domains such as arithmetic compared to word problem solving and geometry would begin to provide the type of information that is needed to construct a developmental model of mathematical ability and disability. Fayol, Abdi and Gombert (1987) suggested that Working Memory is heavily taxed in the process because as WM is drawn on at problem solution stage, as well as the comprehension stage; computational processes must compete with comprehension processes for limited capacity of Working Memory. Hitch and McAuley (1991), and Swanson (1994) demonstrated that difficulties by individual with mathematical learning disabilities are related to difficulties in recording numerical information in Working Memory.

Logie et al. (1994) explored the role of working memory components in mental addition. In Experiment 1, mental addition of auditorily presented two-digit numbers was significantly disrupted by concurrent random letter generation and, to a lesser extent, by concurrent articulatory suppression, but was unimpaired by concurrent hand movement or by presentation of irrelevant pictures. In Experiment 2, the numbers for addition were visually presented. The overall level of performance was better and the absolute size of disruptive effect shown with visual presentation was very small as compared with those found for auditory presentation. This pattern of results is consistent with the role of central executive component of working memory in performing the calculations required for mental addition and in producing approximately correct answers. The data support the view that the sub-vocal rehearsal component of working memory provides a means of maintaining accuracy in mental arithmetic.

In another study, McLean and Hitch (1999) found that different components of working memory may be associated to arithmetic. A probable reason given was that phonological loop might be involved in the
ability to count and hold information while complex calculation is being made (Baddeley & Logie, 1999). Geary, Hoard and Hamson (1999) suggested two possible explanations for the poor working memory in poor arithmetic performance. The first is that many children with arithmetic disability have difficulty with storing facts in LTM and creating an efficient access to the representations. The second explanation is that these children succeed in storing the arithmetic facts but have difficulties in inhibiting the other facts when trying to recall the right answer.

In the memory load version of the dual task method, the participant is given some items to remember (such as letters “b d g h p”), next solves an arithmetic problem such as 42-8, and then reproduces the letters (Seyler, Aschraft, & Kirk, 2003). In the concurrent and memory load methods, performance, when the primary and load tasks are combined (e.g., Arithmetic + Memory load) is compared to performance, when the tasks are done alone. The underlying assumption is that changes in performance in the combined task conditions provide evidence for the involvement of working memory in process. The dual task approach has been used in the literature on math and working memory to explore the working memory demands of simple arithmetic (Hecht, 2002; Seyler et al., 2003) and of multi-digit arithmetic (Fürst & Hitch, 2000). Dual task methods have also been used to test the hypothesis that phonological loop and visual-spatial sketchpad are both involved in mathematical processing (Trbovich & LeFevre, 2003).

Following the dual-task approach, the role of working memory resources in mental multiplication was examined by Seitz and Schumann (2000) in two experiments. Results from the experiments revealed decline in performance on different sums under articulatory suppression but no interference effect was obtained on easy sums. Articulatory suppression and random generation caused a decreased performance on difficult sums. In addition, performance on easy sums was negatively affected by random
letter generation as well. They concluded that solving complex multiplication sums demand phonological loop and central executive processes whereas retrieving numerical facts in solving simple multiplication sums require only central executive processes.

DeRammelaere et al. (2001) investigated the role of phonological loop and the central executive in the verification of the complete set of one digit addition (Experiment 1) and multiplication problems (Experiment 2). The focus of the present study was on the contradictory results concerning the contribution of the phonological loop in the verification of true problems (e.g., 8+4=12 or 4x6=24) reported until then. The results revealed that this slave system is not involved in verifying simple arithmetic problems, in contrast to central executive. Fürst and Hitch (2000) found that working memory demands were greater on carry problems (e.g., 459+876) than on non-carry problems (e.g., 452+241). Thus, as problems increase in complexity like multiple digits, more complex algorithms, and therefore more steps; they are likely to require increased working memory resources.

The role of working memory in arithmetic was also examined by Trbovich and LeFevre (2003). 96 adults solved multi-digit arithmetic problems alone or in combination with either phonological load or visual memory load. The participants solved problem presented in a vertical format significantly faster than those presented in horizontal format. They also solved double digit first problems more quickly than the reverse but only when the problems were presented horizontally. Performance was worse in the phonological load condition than in visual load condition for the participants who solved problem presented vertically. This research provided evidence that both phonological and visual aspect of working memory are involved in mental arithmetic but that the role of each component will depend on factors such as presentation format etc.

Cognitive psychological research has documented lower WMC in children with low math achievement. In particular, the central executive
component of working memory which is responsible for the control, regulation and monitoring of complex cognitive processes appear to be related to individual differences in math ability (Swanson & Beebe-Frankenberger, 2004). This central executive component has been fractioned into separate though overlapping functions – inhibition, shifting and updating. Further, associations between inhibition and mathematical performance have been found in several studies that include either typically achieving children or children with mathematical difficulties. Inhibition is involved in the suppression of inappropriate strategies such as addition when multiplication is required, or suppression of irrelevant information such as information from a context problem that is irrelevant to the problem itself. Inhibitory skills have also been found to reliably predict mathematics scores in typically developing young children. Moreover, inhibition has been found to already predict number sense, as an early form of mathematical proficiency (Kolkman et al., 2013).

Significant unique associations between shifting, a second component of working memory, and mathematical performance have been found in some studies (Andersson, 2007). This relation may be explained by the task demands of many arithmetical achievement tests i.e. children need to switch between operations, strategies and quantity ranges in order to successfully obtain an answer. Also, shifts between different steps of a multi-step problem need to be made to achieve a correct answer in these types of mathematical problems. Other studies, however, have not found a relation between shifting and mathematical skills when controlling for other executive functions (e.g., Monette, Bigras, & Guay, 2011). Blair and Razza (2007) suggested that the lack of explained variance in mathematical performance attributed to shifting in some studies was due to variance already being accounted for by inhibitory control.

Of all executive functions, updating is most strongly related to mathematical performance (Passolunghi et al., 2008). It has been proposed
that updating is involved in the storage and retrieval of partial results in mathematical problems, and remembering important information of the presented problem during the process of problem-solving. A child with insufficient updating skills may forget intermediate results, make procedural errors, or forget one part of the mathematical problem while working on a different part of the problem. Conclusively, updating has been found to be correlated strongly with concurrent mathematical performance and to longitudinal growth in mathematical performance. Updating can be divided into verbal and visuospatial updating. Visuospatial updating has consistently been found to be associated with mathematical performance, whereas verbal updating has been found to have a unique association with mathematical skills in some studies (Navarro et al., 2011), but not in others (St Clair-Thompson & Gathercole, 2006).

Geary et al. (2004) claimed that mathematical disabilities are due to working memory deficits. They investigated children with mathematical disability and their normal typical achieving peers. Tools used were counting span task, counting knowledge task and addition strategy assessment. They found that children with MD have had a WM deficit as assessed by counting span task. Their findings indicated a relationship between WM, counting knowledge and the difference in strategy choices. Their findings also indicated that numerical WM capacity of children with MD is one grade level behind that of their normal peers. The study of Holmes and Adams (2006) provides additional evidence for the involvement of working memory in children's mathematics. It supports the suggestion that working memory assessments may be useful predictors of later academic achievement (e.g., Alloway, Gathercole & Pickering, 2006) and that for impaired, working memory in young children may help to identify those at risk of mathematical difficulties (Gathercole & Pickering, 2001). Evidence for an independent role of the visuospatial sketchpad in early mathematics is important for both cognitive theory and educational practice.
Passolunghi, Vercelloni and Schadee (2007) conducted a longitudinal study to interpret the measures of precursors of mathematics learning e.g., working memory and counting capacities. This study systematically investigates the role of basic cognitive abilities, in the early stages of mathematics learning during the first year of primary school. Particular attention is paid to the precursors of mathematics learning in order to demonstrate the existence of a causal relationship between these cognitive abilities and mathematics achievement. Of the different cognitive abilities, they looked at working memory and short-term memory tasks, phonological ability and numerical competence. As far as working memory is concerned, data supports its role in high level cognition, such as reading and problem solving. The structural linear model confirms the hypothesis that working memory is a distinct and significant predictor of mathematics learning at the beginning of primary school. Word/digit span backward and listening completion span tasks which require storage and processing of information and a main role of central executive component were significant in their impact on performance in the mathematics tests. However, short term memory tasks (such as word/ digit span forward) did not show a causal relationship with mathematics achievement. These results provide substantial evidence for separability of the capacities of short term memory and working memory and also as precursors of early mathematics learning. Results further show that phonological processes specifically relate to number, a precursor of mathematics ability but the phonological awareness is not. It provides substantial evidence for the separability of the two domains of phonological skill and their role in mathematics.

In their prospective study of mathematical ability, Murphy et al. (2007) classified children as MLD if their mathematics score were below the 11th percentile of their sample for at least two years, from kindergarten to third grade, and as LA if their scores were between the 11th and 25th percentiles, inclusive or at least two of these years. Children in these
respective groups not only showed, by definition, lower and higher levels of mathematical performance, but different growth trajectories. Children with MLD started lower on the achievement test and showed more shallow growth, relative to their LA peers and a comparison group of TA children. The LA and TA groups did not differ in terms of growth in mathematics achievement, but their starting points differed by design. Jordan and her colleagues (2006) have also identified classes of children with different initial levels of mathematical competence and sometimes with different growth rates. Results of this study confirm the findings for the existence of a small number of classes of children with different initial levels of mathematical achievement, and findings in terms of class differences in the achievement scores. Jordan et al. (2006) also identified groups with different trajectories across the kindergarten year but focused on growth on mathematical cognition tasks, not achievement measures.

Raghubar, Barnes and Hecht (2010) presented a review of developmental, individual difference and cognitive approaches in working memory and mathematics. They observed the findings across the studies that children with math difficulties differ from children without difficulties, though it could be on verbal working memory composites that sometimes contain numerical information, on static and/or dynamic visuospatial memory tasks, on composite measures of numerical working memory, or on digit span backward in languages with multi syllabic number words. Such findings are clearly of interest to the study of individual differences in mathematics.

To investigate whether working memory is a precursor of individual differences in mathematical achievement, De Smedt, Janssen et al. (2009) conducted a longitudinal study on first grade school children and followed them in second grade. Working memory was assessed in start of first grade and math achievement test was given 4 months later and again one year later. The correlational analyses showed that each working memory
component was predictively related to mathematics achievement in first and second grades. The regression analysis revealed that the visuospatial sketch pad and the central executive predicted unique variance in first grade mathematics achievement. With regard to second grade mathematics achievement, both the phonological loop and the central executive emerged as unique predictors. Both tests of mathematics covered number knowledge, understanding of operations, arithmetic word problems and measurement. However, the second grade test involved more knowledge of the number system, which might be considered as a (symbolic) language. This might explain why phonological loop, rather than visuospatial sketchpad, emerged as a better predictor of second grade mathematics achievement.

Consistent with previous research, findings of De Smedt, Janssen et al. (2009) provide evidence for a relationship between working memory and mathematics achievement in the first and second grades. Their longitudinal correlational design shows that working memory is a precursor of later mathematics achievement which extends the evidence for a concurrent relationship found in cross-sectional studies. Even at the start of formal schooling, working memory has a strong predictive value for later mathematics achievement, therefore working memory assessments at an early age can be valuable diagnostic markers of later mathematics achievement.

Geary, Bailey et al. (2009) carried out a study on 306 school children to study first grade predictor of mathematical learning disability (a latent class trajectory analysis). The students were divided into four groups: mathematical learning disability (MLD) group, low ability (LA) group, and typical ability (TA) group, and high achieving (HA) children. The groups were administered a battery of intelligence (IQ), working memory and mathematics cognition measures in first grade. For mathematical cognition number sense, number sets, number line counting and arithmetic were used; for intelligence Wechsler’s Abbreviated scale of Intelligence was used;
for achievement Wechsler’s Individual Achievement Test II was used, for working memory, WM test battery for children by Pickering and Gathercole was used. The central goals of this study were to identify stable groups of MLD and LA children, to determine similarities and differences in the cognitive deficits contributing to group membership and to identify early cognitive predictors of group membership. Results showed that children with MLD had general deficits in working memory and IQ and potentially more specific deficits on measures of number sense. The LA children did not have working memory or IQ deficits but showed moderate deficits on these number sense measures and for addition fact retrieval. The distinguishing feature for high achieving children were a strong visuospatial working memory, a strong number sense and frequent use of memory based processes to solve addition problems.

Mammarella, Lucangeli and Cornoldi (2010) examined the role of visuospatial working memory and its involvement in arithmetic, in two groups of 7 to 11 year olds. One group comprised children displaying symptoms of non-verbal learning difficulties (NVLD) and the other control group (CG) without learning disability. The two groups were matched for verbal abilities, age, gender and socio-cultural level. The children were presented with visuospatial working memory battery of recognition tests involving visual, spatial-sequential and spatial-simultaneous processes and two arithmetic tasks (number ordering and written calculations). The two groups were found to differ on some spatial tasks but not in the visual working memory tasks. On the arithmetic tasks the children with non-verbal learning difficulties made more errors than control group in calculation and were slower in number ordering. A discriminant function analysis confirmed the crucial role of spatial-sequential working memory in distinguishing between the two groups.
Alloway and Passolunghi (2011) tried to study the relationship between Working Memory, IQ and mathematical skills in children. A sample of 206 seven and eight-year olds was administered tests of these cognitive skills. A different pattern emerged that was dependent on both the memory task and the math skill. In the seven-year olds, visuospatial and verbal memory uniquely predicted performance on the math tests; however, in the eight-year olds, only visuospatial short-term memory predicted math scores. Even when differences in vocabulary were statistically accounted, memory skills uniquely predicted mathematical skills and arithmetical abilities.

Simmons, Willis and Adams (2012) conducted a study to examine whether different components of working memory link with different mathematical skills. A comprehensive working memory battery and test of mathematical skills were administered to 90 children i.e., 41 in Year 1 (5–6 years) and 49 in Year 3 (7–8 years). They found that WM predicts significant concurrent variance in all of the mathematical skills studied. They found that math skills like number writing and symbolic magnitude judgment were more reliant on phonological loop than visuospatial sketchpad. Multiplication accuracy in Year 3 was had strongest unique relationship with phonological loop while addition accuracy in Year 1 had strong unique relation with Central executive processing. They also concluded that visuospatial sketchpad had limited role in mathematical skills involved.

In an effort to understand early numeracy, Clark et al. (2013) conducted a study on pre-schoolers. The sample of pre-schoolers (115 girls, 113 boys), stratified by social risk, completed an Executive Control task battery at 3 years, informal numeracy assessments at 3.75 and 4.5 years, and a broad mathematics assessment during kindergarten. Strong associations were observed between latent Executive Control at 3 and mathematics achievement in kindergarten, which remained robust after accounting for earlier informal numeracy, socio-economic status, language
and processing speed. Relations between executive control and mathematics achievement were stronger in girls than boys. Findings highlighted the unique role of executive control in predicting which children may have difficulty transitioning to formal mathematics instruction.

Recently, Cowan and Powell (2014) studied contributions of domain-general and numerical factors to third-Grade arithmetic Skills and Mathematical Learning Disability. Subsamples of children with MLD (at or below 10th percentile, n=29) were compared with low achievement (LA, 11th to 25th percentiles, n=42) and typical achievement (above 25th percentile, n=187). Examination of these and subsets with persistent difficulties supported a multiple deficits view of number difficulties that most children with number difficulties exhibited deficits in both domain-general (working memory, reasoning, processing speed, and oral language) and numerical factors. The only factor deficit common to all persistent MLD children was in multi-digit skills. The findings also indicated that many factors matter but multi-digit skills mattered most in 3rd grade mathematical achievement.

In another effort in the field, Purpura and Ganley (2014) conducted a study with the focus to determine whether working memory and language were related to only individual aspects of early mathematics or related to many components of early mathematics skills. A total of 199 preschool and kindergarten children were assessed on a battery of early mathematics tasks as well as measures of working memory and language. Results indicated that working memory has a specific relation to only a few but critically important early mathematics skills and language has a broad relation to nearly all early mathematics skills. Interestingly, the specific early mathematics skills that were related to working memory are typically viewed as some of the strongest predictors of later mathematics success (Palmer & Baroody, 2011). They finally concluded that only specific, more complex tasks were better predicted by working memory.
In sum, all components of working memory, including all three executive functions, have been found to be related to mathematical performance. Inconsistencies are often explained using characteristics of tasks and constructs specific to the working memory component. Two general hypotheses regarding the inconsistent relations between executive functioning and mathematics performance were brought forward by Best, Miller and Naglieri (2011). In a large cross-sectional study, they found that different types of mathematical problems were related differently to executive functioning. They proposed that problem solving is strongly dependent on strategy formulation and implementation, and self-monitoring. Calculation, on the other hand, was suggested to be more related to fact retrieval, which requires less executive control. Findings reported by Fuchs et al. (2005) suggested the same. A second hypothesis proposed by Best et al. (2011) was that performance may be related to executive functioning to a different extent in various developmental stages. Age has been reported to moderate the relationship in other studies (Imbo & Vandierendonck, 2007), yielding the primary conclusion that older children rely less on working memory in mathematical problem solving than younger children do, suggesting that part of the inconsistencies between studies may be explained by the age of the participants.

Findings regarding the relations between functioning of the slave systems, which are the visuospatial sketchpad, phonological loop and mathematic skills are also diverse. Whereas, functioning of the visuospatial sketchpad has been found to be significantly associated with mathematics and number sense tasks in some studies (e.g., Andersson & Lyxell, 2007; Krajewski & Schneider, 2009), others have reported only weak or no relations at all (e.g., Rasmussen & Bisanz, 2005). Visual and spatial encoding may make different contributions to mathematical performance. The relation between visuospatial sketchpad and mathematics has also been found to be partially confounded by age i.e., after controlling for age
correlations drop considerably (Kyttälä et al., 2010). It suggests that if studies use a more narrow age range, correlations may not be found. Similarly, functioning of the phonological loop has been found to add unique explained variance to models predicting mathematical achievement (Panaoura & Philippou, 2007; Passolunghi et al., 2008).

Theoretically, the developmental shifts in the memory processes involved in children's mathematics between the ages of 7 and 10 years advances our understanding of how children learn mathematics on two levels. First, the suggestion that young children use predominantly visuospatial strategies until they are competent and able to deploy verbal, abstract strategies is important for the teaching of mathematics. Second, the importance of the visuospatial sketchpad in early mathematics may further deepen our understanding of the deficits experienced by children with mathematical learning difficulties such as developmental dyscalculia. Visuospatial deficits are characteristic among children and adults with mathematical learning difficulties. Understanding that these difficulties may be specifically related to visuospatial working memory deficits in young children provides scope for better early screening methods and opportunities for remediation.

(B) Working Memory and Achievement

Poor working memory has been shown to have measurable impact on educationally relevant measures of children’s performance. It is a common feature of educational underachievement and a substantial majority of children with poor working memory skills fail to meet expected standards in either reading or maths or, most commonly, both. Children recognised by their schools as having Special Educational Needs (SENs) are six times more likely to have working memory impairments than children without SEN (Pickering & Gathercole, 2004). Poor working memory therefore appears to place a child at high risk of poor scholastic achievement as well as attainment.
There is substantial evidence that working memory plays an important role in the development of academic skills in typically developing children. Studies using both experimental and classroom-based designs have shown that deficits in working memory are strongly related to academic underachievement. More specifically, the auditory-verbal working memory system has been linked with the ability to acquire new knowledge and skills, particularly in the development of reading and language but also in mathematics. Visual-spatial working memory has also been implicated as a determinant of children’s learning. For instance, St Clair-Thompson and Gathercole (2006) found visual-spatial working memory was associated with academic attainment in English, mathematics, and science.

There is specific role that WM play for distinct aspects of scholastic performance i.e. reading and mathematics. When it comes to reading comprehension, the involvement of WM has often been demonstrated (Carretti et al., 2009; Swanson & Alloway, 2012). However, the functional role of WM in reading comprehension has been explained in different ways. Depending on whether a WM model with domain-specific subsystems has been applied or domain-general aspects of WM have been emphasized, the role of the phonological subsystem (processing of verbal material) or the role of central executive aspects (integration, inferences) have been proven relevant for reading comprehension.

The ability to read is composed of different processes, such as word decoding, ability to combine words, and draw inferences to comprehend written text. It has been pointed out that the cognitive and environmental determinants of word decoding and reading comprehension are partly different. It seems obvious that verbal WM is especially important for learning to read, whereas Executive Functioning might be more important for later stages of drawing inferences. To read a word, letters have to be sequentially converted into sounds that have to be temporarily stored until all letters have been translated and can then be combined to a word.
Surprisingly, in early stages of acquiring reading skills, the role of verbal WM seems to play a subordinate role whereas phonological awareness seems more important.

Rohl and Pratt (1995) reported on the basis of a two-year longitudinal study with 76 initially pre-reading children that phonological awareness consistently predicted later reading and spelling, whereas verbal Working Memory did not. In contrast, Gathercole, Brown, and Pickering (2003) found that children’s WM scores at school entry (backward digit; naming recall, non-word repetition, word list recall, and word list matching) were highly significant predictors of children’s literacy attainment.

Seigneuric et al. (2000) conducted a study with the aim to study relation between working memory capacity and reading comprehension among the 4th grade children. 48 children were administered with different WM tasks, reading-related skill tasks (vocabulary and decoding). They found that WMC was a direct predictor of reading comprehension when contrasted with vocabulary and decoding skills. Furthermore WM resources involved in reading comprehension were specialized for language processing was described as symbolic system. However spatial task did not correlated in reading comprehension. Likewise, Cain, Oakhill and Bryant (2004) studied the relation between WMC and reading comprehension in 102, 8 to 11 years old children. Participants were assessed for reading ability, vocabulary, verbal skills, and WM assessment. It was found that working memory capacity explained a unique variance in reading comprehension.

Alloway and Gathercole (2005) conducted a study to investigate the extent to which impairment in working memory contribute to severity of children with reading disabilities. 46 participants were tested on the measures of complex memory, verbal and visual STM, IQ, phonological processing, language and mathematics. It was found that severity of reading difficulties was significantly associated with working memory, language and phonological processing whereas poor math abilities were associated with
complex memory score, phonological STM and phonological processing. It was also concluded that association between working memory and reading ability was not mediated by fluid intelligence, STM or phonological processing skills and fluid intelligence shared no independent association with either reading or math achievement.

Swanson et al. (2006) conducted a study to explore relation between components of WM and reading disabilities. They found that children with RD suffer from working memory deficits related to phonological loop which specializes in retention of speech based information. However they also found that in situations that place high demands on processing, individuals with RD have deficits related to controlled attentional processes. In another study, Swanson and Jerman (2006) examined the role of WM components in reading performance. The results showed that controlled attention component was significant related to reading comprehension and fluency as compared to phonological loop of STM. This study supported the notion that deficient growth in executive component of working memory underlies reading disabilities.

For languages with consistent orthographies (such as German), Landerl and Wimmer (2008) have shown in an 8-year follow-up study that phonological WM could predict reading fluency in the 1st grade, but not reading abilities in higher grades or writing skills. These results point to two central aspects that have to be considered in the study of WM and reading abilities: (1) the impact of WM components on reading abilities differs for younger, less skilled and older, more skilled readers; (2) the impact of WM components may differ for languages with consistent (e.g., German, Dutch) and inconsistent orthographies (e.g., English) since a grapheme-phonem correspondence is given in consistent orthographies and phonological recoding is often explicitly instructed.

Carretti et al. (2009) conducted a meta-analytic study to examine the relevance of several WM measures in distinguishing the performance of
poor and good comprehenders. They found that memory tasks such as attentional control and that require verbal information processing are best at distinguishing good and poor reading comprehension performance suggesting that both domain-specific factors as well as general factors of WM contribute to reading comprehension performance.

In another study, Dahlin (2010) examined the relationship between WM and reading achievement of 57 Swedish school children. It was observed that WM training yielded beneficial effects on children’s reading comprehension development indicating that working memory is a crucial factor in reading achievement. Loosli et al. (2012) found similar results in their study investigating the influence of WM training on reading and problem-solving of 66, 9 to 11 years old school children. McVay and Kane (2012) found that mind wandering was a significant mediator in the relationship between WMC and reading comprehension suggesting that WMC-reading comprehension correlation is driven, in part by attentional control over intruding thoughts.

Recently, Wang and Gathercole (2013) investigated the cause of reported problems in working memory of children with reading difficulties. 45 RD children and 46 typically achieving children were matched for age and non-verbal ability. The results indicated that children with reading difficulties are impaired in the central executive component. Also, they had substantial deficits in complex span tasks involving either verbal or visuospatial material.

Another undeniable aspect of academic achievement is mathematics. It is a complex subject, encompassing a variety of abilities and skills, such as solving arithmetic problems (addition, subtraction, multiplication, and division), algebra, geometrics, or word problems. Thus, which component of WM or EF is involved may depend on the type of mathematical skill or ability that is considered, and furthermore, on the strategies children use to solve arithmetic problems. These strategies change with advancing age. In a
process-oriented description of WM's involvement in math, the phonological loop is argued to maintain operands or intermediate results, whereas the visuo-spatial sketchpad "could serve as a space where the problem and its solution could be visually represented" (DeStefano & LeFevre, 2004). Since the central executive is responsible for planning, choosing strategies and sequencing activities, its task may be to keep track of which part of a calculation has already been performed.

The meaning of spatial and verbal processing in solving calculations seems to differ between younger and older children who shift from more procedural-based (e.g., counting) to more memory-based (e.g., fact retrieval) strategies to solve arithmetic tasks (Bull et al., 2008). Supporting this claim, McKenzie, Bull and Gray (2003) found in a dual-task study that 6-year-old children's mental arithmetic was disrupted only by a visuo-spatial passive interference task, whereas the performance of 8-year-old children was disrupted by both a visuo-spatial and a phonological interference task. Recent studies support the notion that whereas younger children rely more on the visuo-spatial sketchpad to solve calculations, older children make more use of the phonological loop (DeSmedt et al., 2009; Krajewski & Schneider, 2009). This pattern of results led some researchers to suggest that "spatial working memory seems to be critical for the learning and application of new mathematical skills and concepts, whereas verbal working memory seems to be more important after a skill has been learned" (Laski et al., 2013).

Lan et al. (2011) conducted a study to examine the relationship between various components of EF like working memory, inhibition and attentional control with academic achievement and how they differentially predict it. The sample was preschool children who performed on EF battery and WJ Test of Achievement. They considered 3 components to academic achievement as simple math, complex math and reading achievement. The results showed that working memory appears to be the most salient
predictor of most aspects of achievement, especially for complex tasks. Inhibition uniquely predicted performance on math achievement tasks that involved relatively simpler processes and attentional control predicted all aspects of achievement. While noticing cultural differences, they noted that in China, working memory was as important for predicting reading as for predicting mathematics, whereas in the United States, working memory was more strongly related to counting and calculation than to reading. Interestingly, they found that Working memory was a unique predictor for reading Chinese but not for reading English. Attentional control predicted reading Chinese very strongly and was a marginally significant predictor for reading English, whereas inhibition did not predict reading in either country.

Henry and Winfield (2010) conducted a research examining whether measures of working memory are related to educational achievement in children with intellectual disabilities (ID). A battery of working memory and achievement measures was administered to 11 to 12 year old children with ID; younger typically developing children of comparable mental age were also assessed. Results showed that phonological STM was a significant predictor of single word reading and spelling in children with ID; whereas central executive of WM was a significant predictor of their number skills. These relationships were broadly similar in typically developing children of the same mental age, suggesting that the structure of working memory and its relationship to academic achievement does not differ markedly in these two groups of children.

In order to explore impact of working memory training on reading and problem solving, Loosli et al. (2011) conducted a study on a sample of 60 school going children (experimental group =20, control group=40, 9 to 11 years). The results showed that WM and reading share overlapping processes. They also showed that it is possible to improve an ability that is very important in everyday life and is related to scholastic achievement in
school-aged children. In another empirical study, Rogers and Tannock et al., (2011) investigated the role of inattention and working memory in predicting academic achievement in 145 adolescents aged 13 to 18 referred for attention deficit/hyperactivity disorder (ADHD). Path analysis was used to examine whether auditory-verbal and visual-spatial working memory would mediate the relationships between classroom inattention symptoms and achievement outcomes. Results showed that auditory-verbal working memory was strongly associated with adolescents’ achievement in reading and mathematics, while visual spatial working memory was only associated with achievement in mathematics. The path from inattention symptoms to reading was partially mediated by the working memory variables, but the path from inattention to mathematics was not mediated by working memory. These findings imply that working memory is a risk factor for academic failure for adolescents with attentional problems.

Recently, Titz and Karbach (2014) tried to illustrate the role of working memory and executive functions for scholastic achievement as an introduction to the question of whether and how working memory and executive control training may improve academic abilities. They confirmed an essential role of WM and EF for academic achievement. Considering its significance for various life outcomes, they suggested that effective interventions that improve academic abilities are desirable. They also concluded that WM and EF training interventions enhance academic performance, in particular with respect to the domain of language and reading.

(C) PASS Cognitive Processes and Mathematical Ability

A growing body of research literature described specific cognitive deficits in students with mathematical learning difficulties (MLD). These students have been found to show deficits in working memory, storage and retrieval of math facts from long term memory, number processing deficits and problem solving skills (e.g., Geary et al., 2000). In traditional tests of
intelligence (e.g., Wechsler Intelligence Scale for children), these students were found to have low scores in performance IQ relative to verbal IQ, low scores on perpetual organization factor and relatively weak performance on digit span (Jordon & Hanich, 2000) based on the population means. A distinction was made between a group of students with math difficulties only and a group of students with both math and reading difficulties, with the latter group showing more specific cognitive deficits.

Alternate approach to intelligence testing, such as the Kaufman Assessment Battery for children and the Cognitive Assessment System, is of obvious relevance for diagnostic and instructional purposes. Because these, theory based tests measure ability as a multi-dimensional concept that may provide more information on specific components and processes than a test designed to measure general intelligence. Cognitive Assessment System (CAS) is such an off-beat test of intelligence, which is based on a theory of PASS cognitive processes. The CAS provides information on student’s strengths and needs. Hence it can be applied on students with learning disabilities. However, the relationship between PASS processes and mathematics has not been explored much and no theoretical framework has been provided linking PASS processes to mathematics. Despite the dearth of research in this area, a few studies have examined the relationship between PASS processes and mathematical ability (Kroesbergen et al., 2009; Naglieri & Rojahn, 2004).

Kroesbergen, Van Luit and Naglieri (2003), focused on a Dutch translation of the CAS, which consists of 12 subtests (3 subtests covering each of the four basic PASS processes. In the study, the relationships between PASS processes and mathematics achievement were investigated. A total of 267 children with MLD were selected on the basis of their low performance (below the 25th percentile). Results showed that students with different types of MLD produce lower PASS scale scores on average than their typically achieving peers and are also more likely to have a cognitive
weakness in planning or successive processing. The students with MLD performed highest on the simultaneous scale among all the scales. Students who had difficulties solving math word problems showed relatively weak attention and successive processing and relatively strong planning and simultaneous processing. Dutch math curriculum consists of word problems so it is understandable that students with a successive processing weakness may encounter difficulties. Although both planning and simultaneous processing are important for the solution of math word problems, these findings suggest that attention and successive processing which play an important role in reading also play a key role in this type of math. Planning is an important cognitive process in mathematics along with simultaneous processing (Naglieri, 2000). In solving math word problems, successive processing also plays a critical role which may explain the lower scores on this scale for the group of students with specific difficulties in solving math word problems. On similar trail, Naglieri and Rojahn (2004) explored the relation between PASS cognitive processes and mathematics and reported that the correlations of Broad Mathematics (Calculation and Applied Problems) with planning, attention, simultaneous, and successive processes were .54, .47, .58, and .45, respectively.

In another study, Kroesbergen et al. (2010) studied kindergarten children in Italy (N=40) and in Netherlands (N=59). The purpose of the study was to investigate the relation between early mathematical skills and cognitive processing abilities as assessed by CAS. In Netherland children enter their kindergarten after their fourth birthday, while Italian children can start their kindergarten much earlier form the age of 2 ½ years and remain until the age of 6 years. The specific goals related to early math included counting objects, images, people and instruction in addition, quantity estimation and classification as it is believed that these activities are interactive and are necessary for later curricula, which require some basics in math concept, understanding of numbers, and knowledge of
numbers. The children in two groups were given early numeracy test and Cognitive Assessment System. The math scores measured with the ENT correlated significantly with the PASS Processes. Together, these four processes explained 46.5% of the variance in early math scores of the children. This is the same amount of explained variance as Naglieri and Rojahn, (2004) found between basic math and the PASS processes in a study with older children (5 to 17 years). The CAS full scale score was highly correlated with both the total scale (r=.69) and the Piaget (r=.64) and counting (r=.59) factors of ENT. The correlation between CAS and ENT total scores did not differ between the groups for both countries (z=1.40, p=.16).

An unexpected result of this study was that successive processing did not play a major role in the counting tasks. It might be reasoned that when counting is not yet automatized, planning and executive strategies are more important for success. A second finding was that simultaneous processes are important in the Piagetian tasks. This may be attributed to the fact that Piagetian tasks are mostly visuospatial hence demand simultaneous processing. It was also found that the Dutch children performed significantly higher than the Italian sample on one successive subtest and the simultaneous scale. A possible explanation for this finding is that simultaneous subtests require processes that have been trained in the cognitive oriented curriculum in Netherlands. In short, it can be concluded that PASS processing and early math performance are related. Different PASS processes appear to relate to different aspects of early math skills. These results suggest that these basic PASS cognitive processes (Planning and Attention) may be useful for early identification of children at risk for later math problems (Kroesbergen et al., 2007).

Iglesias-Sarmiento and Deano (2011) studied the relation between cognitive functioning and mathematical achievement in 114, 4th to 6th grade students. Differences in performance were studied concurrently in three selected achievement groups: mathematical learning disability group (MLD),
low achieving group (LA) and typically achieving group (TA). For this purpose, performance in verbal memory and in the PASS cognitive processes of planning, attention, simultaneous and successive processing was assessed at the end of the academic course. Correlational analyses showed that phonological loop, successive and simultaneous processing were related to mathematical achievement at all three grades. Regression analysis revealed simultaneous processing as a cognitive predictor of mathematical performance, although phonological loop was also associated with higher achievement. Simultaneous and successive processing were the elements that differentiated the MLD group from the LA group. These results show that of all the variables analyzed in this study, simultaneous processing was the best predictor of mathematical performance (Deano, 2000).

A study was conducted to explore link between PASS processes, executive function and achievement by Best, Miller and Naglieri (2011). It was done on a sample of 2036 children with age range 5 to 17 divided into two groups, group one 5 to 7 years old and group two 8 to 17 years old years. The children were given three CAS subtests (matching numbers, planned codes and planned connection) that measure executive functioning and Woodcock-Johnson test of achievement which has nine subtests that assess basic reading, writing, and mathematics knowledge skills. Pearson's product moment correlations were computed between completion time and accuracy, standard performance indices and WJ-R achievement subtest standard score for each age group and between standard performance indices and the general WJ-R categories of math and reading achievement. The pattern of correlation strength between each EF task and achievement across age was remarkably similar for math and reading when considered on the whole. Complex EF correlated significantly with subtests within each domain. This finding supports a previous finding that executive function tasks assess the common cognitive processes (e.g., plan generation, self-
monitoring, updating and impulse control) that are important to both reading and math.

Cai, Li and Deng (2013), in a study on 6th to 8th grade (N= 380) Chinese students, investigated the relationship between PASS cognitive processes, working memory and processing speed among students with mathematical learning disabilities. Correlation among all central executive system tasks, visuospatial sketchpad, and phonological loop, processing speed, planning, attention, simultaneous, successive processing and achievement in mathematics were calculated. The three components of WM were significantly or marginally correlated and the four components of the basic cognitive PASS were also significantly correlated. Academic achievement in mathematics correlated significantly with the working memory and basic cognitive processes yet it was not associated with all three processing speed tasks. In order to study the effects of working memory, processing speed and PASS processes in predicting MLD, forward logistic regression was used. The three components of simultaneous processing, planning, and visuospatial sketchpad all had significant effect in predicting MLD. It seems MLD students have deficits in their central executive system, visuospatial sketchpad, as well as phonological loop. MLD students cannot allocate attention resources effectively in or situation with interference. They have difficulty in coordinating resources for the appropriate task.

Simultaneous processing and planning have been ascertained as the best MLD predictor factors. Simultaneous processing demands individual to integrate all available information. Simultaneous processing is a highly required ability in mathematical tasks because any missing detail might lead to failure to complete the task. In addition to simultaneous processing, planning also has a reaching impact on the mathematics performance of middle school students. Execution and monitoring function of planning are increasingly needed with an increase of difficulty in academic courses.
Working memory, PASS and mathematics scores all have close association.

In a recent investigation by Sarmiento, Gil, Rodríguez and Deaño (2014), the cognitive mechanisms underlying arithmetical achievement in Primary Education 4th-graders were analysed. For this purpose, the Digit Span subtest of WISC-R and the scales from the batteries CAS and BANEVHAR were used to assess the performance in verbal memory, processing speed, planning, simultaneous and successive processing, attention, and numeric competence in 74 students. The correlational analyses showed that, except for planning, all the variables selected were significantly related to arithmetical achievement. Simultaneous and number processing emerged as predictors of arithmetical performance in the hierarchical regression analysis carried out.

Conclusively, the results of the studies examining the unique contribution of PASS processes to mathematics are mixed (e.g., Georgiou et al., in press; Kroesbergen et al., 2009). For example, Kroesbergen et al. (2009) found that PASS processes jointly accounted for 46.5% of the variance in early mathematics, but only planning and simultaneous processing were significant predictors. In contrast, Georgiou reported that PASS processes jointly accounted for 36 percent of the variance in mathematics at the end of Kindergarten and 30 percent of the variance at the end of Grade 1, but none of them was a unique predictor of early mathematics ability (Abougoush, 2014).

Planning

Past researches have indicated that each of the PASS cognitive processes contribute uniquely to mathematical ability. Planning for example, plays a critical role in higher levels of cognitive activities such as problem solving: strategies, plans, and executive functions which are commonly used in describing problem solving behavior. The processes underlying planful behavior relate to all the other processes and components of the PASS
model. Attention, simultaneous and successive processing interacts with planning. Ashman (1978) was first to identify a planning factor among 8th graders and adult mentally retarded subjects. Planning was separated from the factors of simultaneous and successive processing. Planning composition, crack the code, and pharmaceutical problem solving have been used in research. In a research study on adult college students (Das & Heemsbergen, 1983) four tests of planning were used, which were planned composition, syllogistic reasoning, solving Time, visual search and Trail making and Stroop word reading and color naming. The faster the subject can do syllogisms the better is his/her planning. Das and colleagues (1988) studied 15 high school student who were very good on visual search and 15, who were poor and gave them reading tasks. Fast visual search group recalled more sentences as compared to slow searchers.

In a study by Kar (1989), children of grade 5 were classified as high and low planners by taking the top and bottom 15 children each in visual search. They were given number matching tasks under two conditions, standard instructions and verbalization. The high planners displayed a faster rate of number matching than low planners in math (Naglieri & Das, 1997b). They found that planning appears to be specifically related to particular aspects of academic performance, such as math calculation (Das, Naglieri, & Kirby, 1994). Naglieri and Johnson (2000) found the math computation of children with a planning weakness to benefit considerably from cognitive strategy instruction that emphasized planning. Children with no planning weakness who nevertheless received the same planning based instruction, did not show the same level of improvement in math computation as the other children.

Parrila, Das and Dash (1996) carried out a study on 250 students of grade 3,5,7,9, and 11. They were given matching number, planned code, crack the code tasks for measurement of planning, and complete CAS tasks. MANOVA indicated that the main effect of grade was significant, whereas
gender had no significant effect on planning. Pairwise comparisons of performance means between grades indicated that developmental rejections were not uniform across planning tasks. Correlation and regression analyses showed that the relationship between the planning tasks and attention and simultaneous and successive processing scores varied as a function of the planning task and the grade level. Furthermore, two planning factors were found and cluster analyses of variables indicated that one of the tasks, crack the code may represent a different kind of planning than the other two tasks matching number and planned code. Kroesbergen et al. (2003) also reported that planning appeared to play a role in the automation of basic facts in addition.

In another research, Best, Miller and Naglieri (2011) found that the performance of children on planned codes and matching numbers increased with age. They expanded the finding that planning scale correlates moderately with achievement. More specific connections were examined in the study. First importantly, the pattern of correlation strength between each executive function tasks and achievement across age was remarkably similar for math and reading when considered on the whole and complex executive function correlated significantly with subtests within each domain. This is noteworthy because of the very different content of these two academic domains. This finding supports a previous finding that executive function tasks assess the common cognitive processes (e.g., plan generation, self-monitoring, updating impulse control) that are important to both reading and math (Bull et al., 2008). As support, matching number, a task that consists solely of finding identical number (i.e. no letters) correlated as strongly with reading as with math, suggesting that the ability to generate and apply plan, monitor its effectiveness and self-correct as necessary is similarly relevant to both domains. This suggests that math problem solving relies more on strategy formulation and implementation and self-monitoring. Iglesias-Sarmiento and Deano (2011) found the
relation between mathematical achievement and performance on the tests that assess planning, phonological loop and coding among 5th grade children.

Similarly, Cai, Li and Deng (2013) found that planning ability has a far reaching impact on mathematics performance of middle school students. The effect of planning ability on mathematics performance enhances as age increases. This is because of the execution and monitoring functions of planning are increasingly needed with an increase of difficulty in academic courses.

**Attention**

To be attentive implies that the individual is alert. Alertness can be sustained for a period of time and it is selective. Arousal or alertness is common prerequisite for learning and memory. Attention, through its relation to learning and problem solving becomes an essential component of intelligent behavior. The assessment of selective attention more than sustained attention has been useful in distinguishing between groups of special children. Titchner was one of the proponents of structuralism, thought of attention in terms of ‘sensible clearness' or clarity of sensation in 1908. Around 1890, William James, a contemporary of Titchner, thought of attention as a process of selection, simply because we need to select from a large number of stimuli that impinge on us during our waking moment.

Das used Stroop test and the tasks such as those modified from Posner and Boies (1971) as measures of expressive and receptive aspects of selective attention. Both Stroop and Posner tasks are appropriate measure of selective attention in as much as both are measures of discrimination, selectivity and the ability to handle more than one task at the same time. Posner’s ideas for matching pairs of letters which are visually identical (AA, TT etc) and identical in name (Aa, Tt etc) have been used in constructing two sets of task – Picture matching and Letter matching. The Stroop test has been used as a measure of selective attention for hyperactive and learning disabled children (Lazarus, Ludwig, & Aberson, 1984).
As suggested by Das (2001), maintaining a distinction between planning and attention helps with not only conceptual clarity but also with establishing the construct validity and pragmatic validity of the DN-CAS. Conceptually, the PASS model is consistent with Luria’s model of working brain. As suggested by Luria (1966), both at the level of cognition and brain function, attention and planning are separable and carry out separate functions. This idea has been tested by many empirical studies and has been confirmed by these studies results; that is, these two processes are independent of each other and can be further separated by their brain localizations or neural networks. For instance automatic attention is controlled by posterior attention network located primarily in the parietal cortex, whereas executive function depends on the anterior attention network located in the prefrontal cortex (Dietrich, 2007).

Previously, Parilla, Das, and Dash (1996), studied development of planning and its relation to other cognitive process in 250 students from grade 3, 5, 7, 9 and 11. This study tested the significance of attention, simultaneous and successive processing as cognitive correlates of operation planning and action planning. Planning, attention, simultaneous and successive processing are closely interrelated in Luria’s (1973) model of brain functioning. They are also hierarchically organized, and although planning as a cognitive function is always dependent on the functioning of attention-arousal and coding units, the reverse can also be true. What information is attended to, and to what extent, can be influenced by a plan controlling one’s overall approach to the task at hand. It is likely that attention, and simultaneous and successive processing would not have such an impact, at least directly on activity planning. Further Gutentag, Naglieri, and Yeates (1998) identified children with TBI (Traumatic Brain Injury) displaying significant deficits in planning and attention. This explains reasons of disorientation cognitively and physically which are the functions in the forebrain and midbrain among the children with TBI. Also, planning is
said to be associated with the efficient execution and verification of speaking and reading words. Attention corresponds to the alertness to discrete sounds, letters and inhibiting irrelevant stimuli.

Kroesbergen, Van Luit, and Naglieri (2003) found that students who had difficulty in solving math word problems showed relatively weak attention and successive processing and relatively strong planning and simultaneous processing. Although both planning and simultaneous processing are important for the solution of math word problems, these findings suggest that attention and successive processing, which play an important role in reading, also play a key role in this type of math.

In another study, Fein and Day (2004) studied the PASS theory of intelligence and the acquisition of a complex skill which was basically a criterion related validation study of CAS scores. Their findings indicate that CAS can be useful in advancing our understanding of complex skill performance. Regression analysis showed that successive processing and attention were the underlying processes that best explained skill based performance, demonstrating that both higher and lower-order cognitive processes contribute to performance on a complex perceptual motor task. The results for attention scores support the importance of higher-order cognitive processes. These findings extend previous research which showed that attention, another aspect of higher order processing, is an important determinant of complex skill acquisition. An important implication of these findings is that the CAS attention scale could be used to identify attentional demands of complex tasks, or from intervention designed to improve attention management skills.

On the same pattern, Wang, Zhao, Lv and Shen (2008) reported that MLD students have deficits in terms of attention control, inhibition and coordination abilities. In addition they found that MLD students are unable to use the coordinated strategy effectively or allocate attention resource reasonably in the completion of complex tasks that require attention
distribution. These students cannot allocate attention resources effectively in a situation with interference.

From the pragmatic standpoint, by separating planning from attention in the DN-CAS more information about cognitive weaknesses and impairments in children with specific cognitive disabilities can be gathered. This assumption was verified by the study of Deng et al., (2011). As the profiles of the DN-CAS showed, there were large differences in attention (in all three subtests) between the children with ADHD and the normal sample; however a smaller difference (in one out of three subtests) was observed in the planning factor. Similar results have been found in other studies on children with attention problems. In a study on children with low and high attention (assessed by teacher’s ratings and hyperactive in the class) Papadopoulos et al., (2005), found that control group was superior to the children who scored low in attention measures, but not in planning measures. The advantages of the PASS model might also be found in the D-N CAS’s profiles on children with Chinese reading disabilities. The Chinese dyslexic children performed significantly worse than the normal control group did in the planning connections and planning codes subtests (as well as the planning factor derived from the CFA model), but not in any of attention subtests. Therefore in addition to simultaneous and successive processing factors, the planning factor, but not the attention factor, will help to discriminate Chinese dyslexic children from normal children.

Georgiou, Tziraki, Manolitsis and Fella (2013) in a study tried to see relations between rapid automatized naming (RAN) and reading and mathematics, on children from kindergarten to grade 1. Their sample constituted 72 children. Fifteen tests assessing Math abilities, reading abilities and working memory were given to children. They pointed that RAN components did not correlate significantly with response inhibition. RAN requires selection of a verbal response and shifting of attention from one stimulus to the next suggests that at least part of its predictive variance in reading/mathematics could be shared with attentional processes.
Simultaneous Processing

The need to appreciate the relationships among all components of the item is the hallmark of a simultaneous task. Geometrical design progressive matrices, concrete paired associate learning task, block designs, embedded figures, figure memory, comprehension of logical statements, logical grammatical relations have been used in research, to assess simultaneous processing. Luria (1966) states that there is a strong evidence for distinguishing two basic forms of integrative activity of the cerebral cortex by which different aspects of the outside world may be reflected. These two types of processes are simultaneous i.e. integration of stimuli into synchronous and primarily spatial groups and successive, i.e. integration of stimuli into temporally organized serial order.

Fein and Day (2004) found that cognitive learning criteria were associated with different set of CAS scales than skill based criteria. Specifically scores on simultaneous processing made significant and unique contributions to knowledge acquisition; scores on attention contributed to skill based learning. Similarly, Deng, Zuo and Das (2007) observed that MLD students are mainly deficient in simultaneous processing, which demands individuals to integrate all available information. Hence it was concluded by the authors that simultaneous processing is a highly required ability in mathematical tasks because any missed detail might lead to failure to complete the task. In another study, Kroesbergen et al. (2010) found that simultaneous processes are important in Piagetian tasks involved in early numeracy test. This is not unexpected because the presentation of the Piagetian tasks is mostly visuospatial and therefore demands simultaneous processing.

Subsequently, Iglesias-Sarmiento and Deano (2011) found that phonological loop, successive and simultaneous processing were related to mathematical achievement at all three grades. Regression analyses revealed simultaneous processing as a cognitive predictor of mathematical
performance. Simultaneous and successive processing were the elements that differentiated the MLD group from LA group.

Cai et al. (2013) also found that MLD students are less competent in simultaneously storing and processing information due to a deficient central executive function. Logistic regression analysis was applied to examine the PASS predictor power and determined that PASS cognitive processes have divergent effects on the math performance of students. Simultaneous processing and planning were found to be best predictor factor for MLD. These results confirm that simultaneous processing is the most effective indicator of mathematical learning difficulties.

**Successive Processing**

Successive processing involves the integration of stimuli into a particular series where the elements form a chair like progression. Successive processing has been found to be correlated with mathematics achievement, but generally at a lower level than simultaneous processing (Das, 1988). According to Naglieri and Das (1997b) successive processing is important for many academic tasks, but in mathematics, probably most important when the children do not follow the sequence of events and for the memorization of basic math facts. Child learns the information as a serially arranged string of information that makes successive processing especially important. Successive processing is also important for the word reading that are not known by sight and may therefore be particularly important for the solution of math word problems. The group of students with difficulties solving word problems produced relatively lower scores on successive scale and relatively high scores on simultaneous scale (Kroesbergen, Van Luit, & Naglieri, 2003).

Fein and Day’s (2004) study extended empirical research on the planning, attention, simultaneous and successive (PASS) theory of intelligence via CAS, by examining the criterion related validity of CAS scores
with respect to the acquisition of a complex skill. Successive processing was the only CAS scale to explain a unique proportion of variance in all the learning measures.

Kroesbergen et al. (2010), investigated the relation between early mathematical skills and cognitive processing abilities for two samples of children in Italy (N=40) and in Netherlands (N=59) and found that the correlations between successive processes and early math were significantly low than the correlation with full scale. Correlations of Piagetian factor with successive scores were also significantly low.

These finding indicted that PASS processes can be useful in advancing our understanding of complex skilled performance. Regression analysis indicate that successive processes and attention were the underlying processes that best explained skill based performance, demonstrating that both higher and lower order cognitive processes contribute to performance on a complex perceptual motor task.

Numerous aspects of PASS processes have been proven to have high correlation with working memory (Kroesbergen, Van Luit, & Naglieri, 2003). It was found that working memory, PASS, and mathematics scores all have close association, whereas they have low correlation with processing speed. First, the central executive system is closely related to both academic achievements in mathematics and PASS, which also proves the domain generality in the mechanism of the central executive system (St Clair-Thompson, 2011). Working memory can also be presumed to serve as the knowledge base of PASS. Best, Miller, and Naglieri (2011) determined that academic achievement is most related to the central executive function. Two visuospatial sketchpad tasks have a close relationship with simultaneous processing, that is, when dealing with information, the students must integrate visual cues and store the visual information in the temporary space. Sentence span, which measures the phonological loop of working memory, also has significant correlation with word series, sentence
repetition and sentence questions tasks, which measure successive processing. These tasks share the same ability of memory phonological information in the temporary space. However, the difference between phonological loop and successive processing is that the two have different cognitive loads (Cai, Li, & Deng, 2011).

(D) PASS Cognitive Processes and Achievement

Numerous researches have been carried out with main focus on the role of PASS cognitive processes in achievement. Academic achievement, among school children, has been measured mainly in terms of reading and mathematics, though there are other aspects involved as well. DN-CAS scores have been found to be strongly related to achievement (r=.70; Naglieri, 2001), which is quite remarkable as the test does not contain the verbal and achievement components found in traditional measures of IQ tests.

Proficiency in reading demands mastery over two different skills which are word reading and reading comprehension. The two skills of course are highly related yet sub skills within each component and disorders related to reading weaknesses differentiate the two components (Oakhill, Cain, & Bryant, 2003). Researches carried out within the framework of PASS model of intelligence (Naglieri & Das, 1988; 1990) have established that Planning, Attention, Simultaneous and Successive (PASS) processes are importantly involved in reading. Attention being the basic prerequisite of all intellectual functions helps the readers to focus on relevant information to the exclusion of the irrelevant ones and also makes way for efficient coding that may be either simultaneous or successive or both. In fact, a cyclical hierarchy of involvement of both simultaneous and successive processes is seen in the entire process of reading. Successive coding involves sequential processing of linguistic input which serves as a prerequisite for deeper level of semantic analysis of the same that involves simultaneous processing. Mastery over the two skills ultimately makes way
for emergence of appropriate reading strategies in which planning plays a crucial role.

A study by Best et al. (2011) was conducted on a sample of 2036 children with age range 5 to 17, with sample divided into two groups one 5 to 7 years old and group two 8 to 17 years old. The children were given three CAS tests that measure executive functioning and Woodcock-Johnson test of achievement which has nine subtests that assess basic reading, writing, and mathematics knowledge skills. The three subtests of CAS used in this study were matching numbers, planned code and planned connections. Multivariate analysis of variance was performed to determine whether executive functioning performance continued to improve into adolescence on each of the three tasks. Pearson’s product moment correlations were computed between completion time and accuracy, standard performance indices and WJ-R achievement subtest standard score for each age group and between standard performance indices and the general WJ-R categories of math and reading achievement.

On matching numbers children, not adolescents who completed the task more accurately, completed it faster. Starting at age 12, however completion time and accuracy were unrelated. It reflects the fact that accuracy improved very little in late childhood and adolescence but completion time continued to decrease significantly during same period. On planned codes children of all ages used most of the allotted time to complete the task and this limited variation in performance may explain why completion time and accuracy were not strongly or consistently related at most ages. Completion time and accuracy did correlate positively form age 8 to 12 years indicating that children who spent more time on tasks completed the task more accurately. These findings are in consonance with those of Winsler et al. (2006) and Davidson et al. (2006).

As far as relation between executive function and academic achievement is concerned, executive function involves the creation and
implementation of a plan, self-monitoring and cognitive flexibility. Previous research on the CAS reported that the planning scale (a composite of the three EF tasks) correlates moderately with achievement. The pattern of correlation strength between each EF task and achievement across the age was remarkably similar for math and reading when considered on the whole. Complex EF correlated significantly with subtests within each domain. Matching numbers a task that consists solely of finding identical numbers (i.e. no letters) correlated as strongly with reading as with math suggesting that the ability to generate and apply a plan, monitor its effectiveness and self-correct as necessary is similarly relevant to both domains.

The overall correlation of CAS with Woodcock-Johnson Revised Test of achievement skills cluster has been found to be .73. The correlation with mathematical skills have been found to range from .67 to .72 with the highest subscale correlations occurring for simultaneous processes and math (.62), planning and math (.57). These findings suggest that CAS is a good predictor of academic achievement in general and math achievement in particular.

When it comes to relationship of PASS cognitive processes with Reading, there is quite substantial literature is available. Several studies have shown that PASS cognitive processes are related to reading ability (Das et al., 2008; Wang et al., 2012). Despite the plethora of studies documenting that PASS cognitive processes correlate well with reading, the findings of studies that examined the unique contribution of PASS processes to reading are mixed (Joseph et al., 2003; Naglieri & Rojahn, 2004; Papadopoulos, 2001). For example, Joseph et al. (2003) showed that the PASS processes together accounted for 36 percent of the variance in basic reading skills (Word Identification and Word Attack). However, only simultaneous processing among the PASS processes was a significant predictor of reading. On the other hand, Das et al. (2007) found that the PASS processes
accounted for 26 percent of the variance in Word Identification and 29 percent of the variance in Word Attack, but only successive processing was a significant predictor of both reading skills (Abougoush, 2014).

Similarly Das, Naglieri and Kirby (1994) found that children with reading decoding failure and phonological coding problems perform poorly in Successive processing and are associated with assembly of correct sounds in order which demands Successive processing. On the other hand, student who scores high in Planning aware of the task strategy relationship and monitors strategic success which are two essential aspects of metacognition. According to Naglieri (1999), PASS processes are being associated with phonological components of spoken and written language. Planning is said to be associated with the efficient execution and verification of speaking and reading words. Attention corresponds to the alertness to discrete sounds and letters, and inhibiting irrelevant stimuli. Successive processing is associated with sequentially decoding the sounds in words or making one to one correspondences with letters and sounds. Simultaneous processing is associated with surveying all the elements of a word and acquiring the sound and letter patterns in a rather hierarchical manner (i.e. understanding that certain letters cue the sounds of other letters in words – such as ‘e’ at the end of the word ‘came’ cues the reader to say the ‘a’ as a long vowel sound).

In another study, Naglieri and Rojahn (2004) examined the relationship of PASS processes with different reading measures in a large scale study with 1559 children ages 5 to 17. The correlations of Broad Reading (Letter-Word Identification and Passage Comprehension) with planning, attention, simultaneous, and successive processes were .48, .43, .55, and .50, respectively. Shamita, Das, Stack-Cutler and Parrila (2009) found that the relationship between word reading and reading comprehension significant ($r = .81, p < .001$), but both skills were significantly related to simultaneous processing ($r = .62$ and $r = .75, p < .001$,
respectively) as well as the overall intellectual functioning (Full Scale) of the children ($r = .44, p = .02$ and $r = .48, p = .01$). These results suggest that reading proficiency, as well as improvement in reading proficiency, is partly determined by one's proficiency in specific cognitive processes as reported in previous studies (Das, Naglieri & Kirby, 1994). However, when both word reading and reading comprehension reach levels above the norm for the appropriate grade, as in the normal reading group, the two skills may become more independent of one another.

According to PASS theory of Intelligence, successive processing predicts reading through the effects of phonological recoding and simultaneous processing predicts reading through the effects of orthographic knowledge (Das, Naglieri et al., 1994). The idea is rooted in the way reading develops. At the beginning of reading development, word recognition is achieved through phonological recoding, which involves the identification of the individual letters in words, retrieval of their corresponding sounds, storing of the sounds in short-term memory and blending of the sounds in serial order. These steps require successive processing. However, access to a direct visual route is also necessary for efficient word recognition in English. This is achieved with the use of orthographic knowledge. The orthographic processing tasks (e.g., Orthographic Choice) require that phonologically similar letter strings (e.g., $rain – rane$) are compared simultaneously (Mahapatra, 2015).

Papadopoulos (2001) showed that Speech Rate, Sentence Repetition and Word Series (indicators of successive processing) predicted reading accuracy (Word Identification and Word Attack) in Grade 1 in Greek, but their effect was mediated by phonological awareness. Likewise, Wang et al. (2012) found that the effect of simultaneous processing on reading (Character Recognition) in Grades 3–5 Chinese children was mediated by orthographic knowledge. Hence it was concluded that successive processing predicts reading through the effects of phonological recoding and
simultaneous processing predicts reading through the effects of orthographic knowledge (Naglieri & Das, 2005). Planning and attention play an auxiliary role, namely they allow the deployment of the proximal cognitive skills (phonological awareness and orthographic knowledge).

Joseph, McCachran and Naglieri (2003) studied the relationship among cognitive processing, phonological processing and basic reading skill performance. The subjects of study showed the same characteristics of lower successive processing score. This could be explained by the predictor of phonological memory was strong related to the successive processing. The research findings also indicated that there were significant relationships between simultaneous processing, letter-word identification and word attack. There were also significant relationships between planning and letter-word identification. Moreover, the study showed the two cognitive processing which are successive and simultaneous are related to the decoding process in reading where it comprises of phonological processing. The best predictor of phonological memory was successive processing. The particularly strong relationship between successive processing and phonological memory occurred due to the similar nature of the tasks that comprise these scales. The items on both scales require children to recall information in a serial order. Thus the overlap between phonological memory and successive processing measurement tasks makes it difficult to distinguish between phonological and cognitive constructs.

Wang, Georgiou and Das (2012) conducted a study to examine the contribution of PASS (Planning, Attention, Simultaneous, and Successive) processes to Chinese reading accuracy and fluency. 140 Mandarin speaking children from Grade 3 to 5 children were assessed on measures of PASS processes, phonological awareness, and orthographic knowledge. A year later they were assessed on reading accuracy and fluency. The results indicated that successive processing predicted reading through the effects of phonological awareness and simultaneous processing predicted reading
through the effects of orthographic knowledge. The results were similar for reading accuracy and fluency. The results verified the predictions of the PASS theory: successive processing predicted reading through the effects of phonological awareness and simultaneous processing predicted reading through the effects of orthographic knowledge. Thus, it could be argued that both successive and simultaneous processes are needed in parallel in Chinese reading.

Despite the long history of PASS theory of intelligence as it relates to reading, there are still few issues that have not been resolved (Chan & Nunes, 2001). First, although the theory assumes that phonological processing is predicted by successive processing and orthographic knowledge is predicted by simultaneous processing, none of the existing studies has included any measures of orthographic knowledge, defined as knowledge of character structure and radical. Likewise, there are studies that have only examined the direct effects of the PASS cognitive processes on reading without including measures of phonological processing or orthographic knowledge. In one of the researches, Leong, Cheng, and Das (1985) showed in a cross-sectional study with Chinese readers in Hong Kong that in Grade 4, reading was predicted by simultaneous processing and, to a lesser extent, by successive processing. In Grade 6, there was a shift in processing strategies; successive processing accounted for more variance than simultaneous processing. Although this early study by Leong and colleagues did establish an important connection between reading and simultaneous–successive processing, it is still unknown whether PASS processes would predict reading if phonological awareness or orthographic knowledge were taken into account. Another issue involved is that none of the existing studies has examined the relationship between PASS processes and reading fluency, which is one of the primary goals of reading instruction beyond the early grades.
Research evidence shows that in a group of 14 to 17 year old students, planning did not account for any unique variance in reading comprehension, when entered in multiple regressions with the rest of the PASS processes (Naglieri & Rojahn, 2004). In contrast, Best et al. (2011) reported significant correlations between planning and reading comprehension up to the age of 17.11 years (r's ranged from .33 to .41 in a sample of 16 to 17, 11-year-old students). Taken together, it is possible that planning is related to reading comprehension, but its predictive variance overlaps with that of attention and simultaneous processing (Deng et al., 2011).

Studies based on PASS theory of cognitive processing (Perez & Timoneda, 2007) have clearly shown dysfunction in successive processing in disabled readers. The relationship of reading to simultaneous and successive processing skills varies in early and later stages of reading acquisition. Though successive processing might have a greater role in the early stages of reading, simultaneous synthesis would be more important at higher grades (Prakash, 1987). Children with reading difficulties have shown deficits in simultaneous and successive processing, which underlie difficulties in phonologic and visual coding (Tripathi & Kar, 2009). Several important studies have validated PASS theory and its link to cognition, intelligence, and reading (Das et al., 2013; Papadopoulos et al., 2014). Studies on non-alphabetic orthographies such as Kana (Nakashima et al., 2012) and Chinese (Wang, Georgiou & Das, 2012) have also demonstrated the efficacy of successive and simultaneous processing skills in predicting reading. They concluded that successive processing predicted reading through the effects of phonologic awareness and simultaneous processing predicted reading through the effects of orthographic knowledge. This premise supports that PASS theory applies reading acquisition across languages. Further, many studies (Dash & Dash, 2011) have elicited that reading involves planning, attention, and simultaneous as well as successive
processing. They have documented the importance of the coding processes, i.e. successive and simultaneous processing in reading.

Recently, Nishanimut and Padakannaya (2014) conducted a study to compare and contrast the cognitive profiles of children with and without reading disabilities in Kannada using CAS. The results showed a significant difference between children with and without RD on all the components of CAS and the full-scale scores. Successive processing was seen as the crucial deficiency in children with RD in English. In this study, the results indicated that children with RD were poor in both simultaneous and successive processing skills. We found no significant difference in performance on CAS between the male and female participants of the NRD and RD groups, suggesting that gender did not have any effect on the scores.

In another recent research, Georgiou and Das (2014) examined how Planning, Attention, Simultaneous and Successive (PASS) processes predict reading comprehension in a sample of university students and what PASS processes distinguish adults with and without reading difficulties. In the first part of study, 128 university students were tested on Das-Naglieri Cognitive Assessment System, reading fluency, and reading comprehension whereas for second part, university students with \( n = 20 \) and without \( n = 23 \) reading difficulties were assessed on the same measures. The results of path analysis indicated that successive processing predicted reading comprehension only through the effects of text- and word-reading fluency, whereas simultaneous processing predicted reading comprehension both directly and through the effects of text-reading fluency. The results of group comparisons indicated that the university students with reading difficulties were experiencing cognitive weaknesses primarily in successive processing. Results reveal that the fluid-crystallized division has less explanatory power than simultaneous and successive processing, as simultaneous processing includes both fluid and crystallized abilities. Specifically, Verbal Spatial Relations measures the same process as Nonverbal Matrices; the former is
crystallized, the latter fits the concept of fluid abilities. PASS theory would have no difficulty in arguing why simultaneous processes may explain reading comprehension because the essential characteristic of simultaneous processing is processing logical–grammatical relationships.

Studies further indicate that planning did not predict reading comprehension and none of the poor readers had solely a planning deficit. Those who had a planning deficit also had another deficit (e.g., attention or simultaneous processing). Authors considered it as an important finding because it helps in better understanding of somewhat conflicting findings of earlier studies (e.g., Best et al., 2011; Naglieri & Rojahn, 2004). The non-significant contribution of planning to comprehension can be attributed to two factors: first, it may be related to what other PASS processes are considered in the regression equation. When planning is used as a single predictor of reading, it accounts for a significant amount of variance. Planning correlated significantly, albeit weakly, with reading comprehension in our study as well ($r = .25$). However, when considered together with the rest of the PASS processes, its effects may disappear. This explanation is in line with Naglieri and Rojahn’s (2004) findings in a group of 14- to 17-year-old students. An additional explanation related to the planning measures used in this study was also proposed. For example, Parrila, Das and Dash (1996) showed that there are two clusters of planning measures, simple and complex, and that the relationship of planning with the rest of the PASS processes varies as a function of the complexity of the planning tasks. Das, Snart and Mulcahy (1982) also found a positive relationship between planning and reading comprehension, when planning included complex tasks, such as planned composition and syllogistic reasoning.

However, Gayo, Deano et al. (2014) investigated a study related to planning. They analysed the effects of an intervention on reading comprehension and planning in 5th and 6th grade students, and determined
the maintenance of the effects of the intervention on reading comprehension and planning. They found that Textual strategy instruction favors reading comprehension and the progressive development of planning, which is necessary for supervision and regulation, and its effects are maintained over time. It was concluded that planning is also necessary to supervise and regulate reading skills.

Intervention studies that focused exclusively on planning have also shown a positive outcome on children's mathematics ability (Naglieri & Johnson, 2000). Naglieri and Gottling (1997), for example, found that when two groups of students (poor in planning and high in planning based on D-N CAS) were given eight weeks of instruction in planning the poor planning group improved in their mathematics performance more than students who did not score poorly in planning.

(E) Working Memory and Intelligence

Over the span of last hundred years, those involved in area of Intelligence theories and researches on intellectual abilities have sensed and accepted the relation between memory and intelligence. As noted by Carroll (1993), Spearman had relatively little use for the construct of memory in his theory of intelligence. Spearman and Jones (1950) argued that insufficient evidence existed to establish memory as an ability factor. Later, Spearman reviewed and reanalyzed data presented by Simpson. In Spearman's (1914) reanalysis, he found that the Ebbinghaus Completion Test, when combined with other verbal and memory tests, had extremely high correlations with the general factor ($r=.95$), although tests of verbal memory had slightly higher correlations. Hence the defining characteristics for ‘g’ shifted from the concept of various abilities to a notion that ‘g’ represented a “general fund of mental energy.”

Among the group factor theorists, Kelly (1928) provided evidence for a common factor underlying memory span tests. When corrected for
unreliability, the correlations among four memory tests ranged from .54 to .96. These tests correlated reasonably well (rs=.39 to .66) with a General Ability factor but also had substantial residual correlations with a separate Memory factor (rs=.46 to .56), leading him to assert that Memory was a separable group factor from general intelligence. Thurstone included a Memory factor in his “Primary Mental Abilities” in 1938, though it was not based on span tests. Subsequently, Guilford (1956, 1967) proposed a “Structure of Intellect” model that expanded the number of group factors. In Guilford’s model, there were 24 separate Memory ability factors (e.g., Brown, Guilford, & Hoepfner, 1966).

In the Hierarchical Models of Intelligence, Cattell (1943) introduced the concepts of fluid intelligence (gf), which is associated with physiologically based abilities, and crystallized intelligence (gc), which is associated with educational and experiential knowledge, as two major factors of adult intelligence. With respect to immediate memory in the gf-gc theoretical framework, Horn (1965) noted that a Memory Span factor loaded positively on the gf factor (r=.38) and negligibly on the gc factor (r=-.02). He reported an average memory span factor coefficient across several of his own studies as .50 with gf and .00 with gc. Later additions by Horn (1989) include a major factor of “short-term acquisition and retrieval (SAR). Interestingly, he asserted that the “backward span memory test . . . is a considerably better measure of gf and consequently a poorer measure of SAR than is forward span memory”.

Baddeley (1999) concluded that long-prevailing term immediate memory was better considered as a Working Memory system, with a central executive and two slave systems - phonological loop and visuospatial sketchpad. Investigations of individual differences in Working Memory led several investigators to propose that WM had key importance for understanding the nature of individual differences in intelligence. The movement to relate WM with intellectual abilities started with Daneman and
Carpenter’s study in 1980, which indicated significant correlations between measures of verbal WM and reading comprehension. Later, Kyllonen and Christal (1990) demonstrated substantial overlap between measures of WM and reasoning abilities. In the decade that followed the Kyllonen and Christal article, claims of overlap between WM and intelligence increased in frequency and in scope of the argument, resulting in the strongest assertion that WM is the same as gf or ‘isomorphic’ to g.

The first investigation of the individual-differences correlates of Working Memory measures was provided by two small studies of reading comprehension (N=20 and N=21) reported by Daneman and Carpenter (1980). WM was assessed by the reading span method, which involves reading a series of sentences and later being asked to recall the last word of each sentence. They found a substantial correlation (.72) between the WM measure and the reading comprehension measure. However, this correlation was likely much higher than would be obtained if the measures did not share common content or method variance. Subsequent studies (e.g., Baddeley, 1986; Daneman & Merikle, 1996) that used a wider variety of WM measures reported significant but relatively smaller correlations between Working Memory and reading comprehension.

In another influential series of empirical studies, Kyllonen and Christal (1990) addressed the question of the relationship between measures of WM, reasoning, general knowledge, and processing speed. Although the central message of their article was that “reasoning ability is little more than working memory capacity”, some different interpretations were also made. The first issue noted by the authors was that the Reasoning factor had a higher correlation with the Knowledge factor than did the WM factor. The second issue noted by the authors was that the Working Memory factor had a higher correlation with a Processing Speed factor than did the Reasoning factor. Thus, while a strong association (r=.80 to .90) was found for a factor underlying computerized measures of WM and a factor
underlying computerized measures of Reasoning, the evidence was also supportive of a differentiation between these factors, on the basis of convergent and discriminant validity with General Knowledge and Processing Speed.

One investigation that provided important insights into the relations between Working Memory and intellectual abilities was reported by Oberauer et al. (2000). These investigators collected data on 23 WM tests that were created within a taxonomic framework. These tests were administered to a sample of 128 participants, along with a battery of 45 ability tests, which were selected from a taxonomic framework similar to that of Guilford. They derived three WM factors from the 23 tests—a Verbal/Numerical WM factor (including simultaneous storage and transformation and coordination functions), a Spatial-Figural WM factor (storage and transformation and coordination), and a third factor that contained WM tests that involved supervisory functions but that were also highly speeded. In linking the WM factors with the intellectual ability scales, authors found correlations between Verbal/Numerical WM factor scores and a numerical test composite of .46 and correlations between Verbal/Numerical factor scores and a reasoning test composite of .42. The Spatial-Figural WM factor scores correlated highest with the reasoning test composite (.56), the spatial test composite (.52), and the numerical test composite (.48). The Supervisory/Speed WM factor correlated at .61 with a speed test composite from the intellectual ability test battery. However, all three WM factors correlated significantly with the speed test composite. These results further suggest that the relationship between measures of WM and intelligence may be more complex than previously considered. That is, WM factors may have a differentiated pattern of correlations with factors of reasoning, content abilities (such as verbal, numerical, and spatial), and perceptual speed (PS).
Subsequently some investigators embraced a view that WM and ‘g’ represent identical constructs. Kane and Engle (2002) stated that WM-capacity measures require a variety of different processing skills and present a variety of stimulus types, correlate substantially with fluid ability tasks across verbal, mathematical, and spatial domains. In addition, they asserted that “there are simply too many strong correlations among diverse WM-capacity tasks and diverse higher order tasks to deny that some general mechanism is involved.” Then a revised conclusion was asserted by Conway, Kane and Engle (2003) which stated that WMC accounts for at least one third and perhaps as much as one half the variance in $g$” and hence WMC and $g$ are indeed highly related, but not identical.

The study by Ackerman et al. (2002) further examined the relations between Working Memory and Intellectual abilities and provided an additional perspective on the specific relations between WM and Problem Solving abilities. They administered 36 ability tests together with 7 WM tests to a sample of 135 adults and found that a single underlying WM factor correlated substantially with a g factor ($r=0.70$), but the WM factor also correlated highly with a general PS factor ($r=0.55$). In addition, they examined differential relations between WM, performance on the Raven test, and a g-composite that did not include Raven test performance. The Raven test correlated .58 with a broad g-composite, while the WM composite correlated .47 with the g-composite. In contrast, the Raven correlated only .25 with a PS composite, whereas the WM composite was significantly more highly correlated with the PS composite ($r=0.47$).

Ackerman, Beier and Boyle (2005) conducted a meta-analysis of 86 samples that relate Working Memory to Intelligence. They used a pair-wise combination of 10 WM related search terms and 10 Intellectual Ability search terms. The meta-analysis conducted in the article clearly demonstrates that WM measures are significantly correlated with measures of intellectual abilities, in terms of broad content abilities (verbal, numerical,
and spatial), with general and specific content-based reasoning abilities, with Problem Solving (PS) and Elementary Cognitive Tests (ECTs), with knowledge abilities, and with \( g \). However, even when the measures are corrected for unreliability, in no case did the estimated true-score correlations between WM and ability exceed a value of .653, indicating a maximum shared variance of 42.6 percent. On average WM tests correlated .364 with measures of \( g \). Correction for unreliability of WM and \( g \) measures increased the average correlation between WM and \( g \) to .479, yielding shared variance of 22.9 percent. They concluded that WM is not the same thing as \( g \) and rejected the claim of isomorphism between WM and \( g \) but they also accepted that WM measures are related to intellectual abilities, though at a far more modest level than unity.

Conway, Cowan, Bunting et al. (2002) investigated the relationship between \( gf \) and STM, WMC and processing speed. Among all the issues, they also examined the territory of relationship between WMC and \( g \). They found a strong link between WMC and general fluid intelligence. According to the authors, there were two possible explanations behind this relationship. They concluded that demand for controlled attention and strong influence of strategy deployment on all the tasks could explain the link between WM and \( g \).

Later came a phase of curiosity among researchers about role of WM and STM in predicting intelligence. Unsworth and Engle (2005) conducted a study to examine the correlation between a measure of working memory capacity (Operation span) and measure of fluid abilities (Raven Advanced Progressive Matrices) on a sample of 160 participants. They found that relation between Operation Span and RPM is fairly constant across levels of difficulty, memory load, and rule type. The shared variance between these types of intelligence tests and working memory capacity may be due to the fact that susceptibility to Proactive Interference is an important source of individual differences in both.
In another study, Unsworth and Engle (2007) used meta-analysis to observe the extent to which STM and WM as measured by Simple and Complex Span task, do they represent the same or different constructs, and the extent to which they demonstrate similar correlation with measures of higher order cognitive abilities. They concluded that simple and complex span largely measure the same basic processes, and rejected the notion that STM and WM are different constructs. Rather, they suggested that all immediate memory tasks measure the same basic processes, accounting for their predictive power across a wide range of tasks. However, the extent to which a particular task measures all of these abilities is determined, in part, by the scoring procedure and the presence or absence of other processes (e.g., rehearsal) that may affect performance.

Subsequently, researchers studied and explored as to why working memory and intellectual abilities are related. Heitz, Redick et al. (2006) clearly stated that WM and gf are separable but highly related. On the basis of a research suggesting common link between WM and gf being Pre-frontal Cortex (PFC) functioning, they concluded that mechanism behind this particular relationship is Controlled Attention- an ability that is dependent on normal functioning of PFC. Colom, Abad, Quiroga et al. (2008) tried to answer the same question as to why working memory and general factor of intelligence are related. They found that working memory and intelligence are highly related because they share capacity limits. These limits refer to both the amount of information that can be temporarily retained in a reliable state (short-term storage) and the ability to update the relevant information. Both mechanisms could rely on discrete brain regions belonging to frontal and parietal areas. Burgess, Gray, Conway et al. (2011) found that the relationship between WM span and gf can be linked, in part, to a common dependence on mechanisms of interference control that reflects activation in a core set of brain regions centered on the lateral PFC and Parietal Cortex.
The body of work reviewed thus far suggests that there is likely not a single factor that accounts for the relation between WM and gf. Specifically, although attention control, capacity, and retrieval from secondary memory, were all found to account for some of the relation, none were found to fully account for the relation. This suggests that the relation between WM and gf is multifaceted in that a number of processes are likely important. It was suggested that WM is represented by both primary and secondary memory components (Unsworth, Spillers, & Brewer, 2010). Primary memory reflects both the number of items that can be distinctly maintained and attention control processes that actively maintain those items and prevent attentional capture. Secondary memory reflects the need to retrieve items that could not be maintained in primary memory as well as the need to retrieve other relevant information from secondary memory. According to this multifaceted model of WM, there are multiple sources of variance within WM measures, and multiple sources of variance that account for the relation between WM and gf (Unsworth, Brewer, & Spillers, 2009; Conway & Getz, 2010). Likewise, Cowan et al. (2006) suggested that both capacity and attention control would be important sources of variation.

Recently, Unsworth, Fekuda et al. (2014) tested whether multiple factors like capacity, attention control, and secondary memory would collectively account for the relation. A large number of participants performed multiple measures of each construct and latent variable analyses were used to examine the data. The results demonstrated that capacity, attention control, and secondary memory were uniquely related to WM storage, WM processing, and gf. Importantly, the three factors completely accounted for the relation between WM (both processing and storage) and gf. Thus, although storage and processing make independent contributions to gf, both of these contributions are accounted for by variation in capacity, attention control and secondary memory. Hence it was concluded that individual differences in capacity, attention control, and secondary memory jointly account for individual differences in WM and its relation with gf.
There also exists accumulating interest and research in cognitive training, especially WM training. Numerous studies have reported training and transfer effects as a result of WM, executive function, and attention type training, most of which were done in young children or the older adult population. Some found improvements in fluid reasoning after training on WM in older adults (Borella, Carretti et al., 2010). WM training studies done on old adults impacted memory performance, a near transfer effect, and these studies did not report significant improvements on gf tasks. Li and colleagues (2008) reported no far transfer effects from WM training to complex span tasks and did not report improvements in measures of IQ. There were also attempts to raise intelligence through improving WM processes by Morrison and Chein (2011).

Bergman Nutley et al. (2011) reported consistent near transfer effects in their study on 4-year old children. The authors observed improvements on reasoning tasks in children that trained on reasoning skills, and they failed to find transfer effects from WM training to reasoning and fluid intelligence tasks. More examples of near transfer effect included a study by Mackey et al. (2011), and Thorell et al. (2009) that reported near transfer effects but neither far transfer effects nor improvements in IQ measures. Holmes, Gathercole, and Dunning (2009) reported no boost in IQ performance in children with low working memory capacity. Review by Diamond and Lee (2011) on cognitive training conducted on children concluded that only core executive function – WM, cognitive flexibility and inhibition – training is most beneficial to 4 to 12 years old. Nevertheless, researches have been successful in establishing strong link between WM and intelligence and possible explanations behind this link like attention control, secondary memory and capacity yet there is lot to be further explored and investigated.

It is quite clear from the review of related research that working memory and PASS cognitive processes contribute significantly in
mathematics as well as in achievement among children. Further, relation between working memory and intelligence has been established by previous studies. In particular, more interest has been shown by psychologists in the relation between working memory and fluid intelligence which is attributed to attentional control and secondary memory (Unsworth et al., 2014), collectively. Although, main focus of this research was to examine whether Working Memory and PASS Cognitive Processes contribute to differences in low and normal mathematical ability children yet an underlying issue is that this prediction of mathematics by working memory might be affected by intelligence with PASS theory being an alternative approach to intelligence.