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ASSESSMENT AND REMEDIATION FOR CHILDREN WITH SPECIAL EDUCATIONAL NEEDS:

THE ROLE OF WORKING MEMORY, COMPLEX EXECUTIVE FUNCTION AND METACOGNITIVE STRATEGY TRAINING

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ABSTRACT

The overall aim of this thesis was to explore the role of different assessment tools and training regimens in assessment and remediation for children with special educational needs in school. A central purpose of assessment explored was that it should inform remediation, teaching and instruction. The concepts of working memory, complex executive function and metacognitive strategy training for children with special educational needs were specifically explored in relation to this purpose of assessment. Complex executive function refers to planning and metacognitive ability, that many children with special educational needs struggle with, and which they are expected to handle in learning during school day. Of particular interest in the thesis was the contrast between working memory and complex executive function and how these concepts inform assessment and remediation practices. In this context, special attention was given to mathematical learning difficulties.

The thesis was based on four studies (I-IV). Study I explored the prevalence of different assessment tools, and dilemmas and challenges as perceived by assessment professionals, teachers and parents, in the work with children with special educational needs in Europe. In Study II, a metacognitive strategy training framework was developed as a training regimen, guided by research on complex executive function, and applied on working memory training. Effects of working memory training were compared between the two training regimens, with and without metacognitive strategy training, and also the overall effect of working memory training on cognitive functioning and the school related skills of reading, writing and arithmetic. In Study III, different types of measures of working memory and their predictive capacities in relation to mathematics achievement in national curriculum assessments were explored, as well as the effects of working memory training on mathematics achievement. In Study IV the role of working memory and complex executive function in identifying risk for mathematical learning difficulties in children with special educational needs was explored.

The results from Study I suggested that assessment and remediation practices can contribute to a deficiency-oriented outlook on children with special educational needs. In contrast parents and teachers in Sweden also reported that assessment could help them to better understand the needs of the child. Results from studies II-IV showed that only the use of a metacognitive strategy training regimen targeting complex executive function resulted in improvements following working memory training. The results also indicated that working memory training strongly predicted mathematical performance in national curriculum assessments of mathematics in school, and that a more complex change measure of working memory was a better predictor than simple working memory measures in this regard. Finally, the results also showed that complex executive function, defined as planning ability, was a better predictor than simple working memory in the assessment of risk for mathematical learning difficulties.

The results from the studies were discussed in relation to the purpose of assessment to inform remediation, teaching and instruction for children with special educational needs. It was concluded that, in addition to working memory, as complex executive function – planning and metacognitive ability - seems to be an important cognitive function related to learning, this should be addressed both in the assessment of children with special educational needs as well as in the remediation when designing training regimens and interventions for children with special educational needs in general, and children at risk for mathematic learning difficulties in particular. It was also highlighted that in remediation, the role of the teacher as a mediator of metacognition and complex executive function seems vital.

Keywords: Children with special educational needs, Assessment, Working memory, Working memory training, Complex executive function, Planning, Metacognition, Mathematical learning difficulties.

UTREDNING OCH STÖDINSATSER FÖR BARN I BEHOV AV STÖD:

VILKEN ROLL SPELAR ARBETSMINNE, KOMPLEX EXEKUTIV FUNKTION OCH METAKOGNITIV STRATEGITRÄNING?

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SVENSK SAMMANFATTNING

Det övergripande syftet med avhandlingen var att undersöka den roll som olika utredningsverktyg och begrepp spelar i utformandet av utrednings- och stödinsatser för barn i behov av stöd i skolan. Ett centralt syfte med utredningar som utforskades är att de ska bidra med kunskaper vid utformande av stödinsatser och undervisning. I relation till detta syfte utforskades specifikt begreppen arbetsminne, komplex exekutiv funktion och metakognitiv strategiträning för barn i behov av stöd. Komplex exekutiv funktion syftar till planerings- och metakognitiv förmåga, något som många barn i behov av stöd upplevs ha svårigheter med, och som de förväntas kunna hantera i lärandet i skolans vardag. Av särskilt intresse i avhandlingen var kontrasten mellan arbetsminne och komplex exekutiv funktion och hur dessa begrepp bidrar till en förståelse i utformandet av utrednings- och stödinsatser. I detta sammanhang uppmärksammades särskilt matematiksvårigheter hos barn i behov av stöd.

Avhandlingen bygger på fyra studier (I-IV). I Studie I undersöktes förekomsten av olika utredningsverktyg, samt utredares, lärares och föräldrars uppfattningar av dilemman och utmaningar i arbetet kring barn i behov av stöd, i Europa. I Studie II utformades ett koncept för metakognitiv strategiträning med utgångspunkt från forskning kring komplex exekutiv funktion och tillämpades i arbetsminnesträning. Effekten av arbetsminnesträning med och utan metakognitiv strategiträning jämfördes, liksom effekten av arbetsminnesträning på kognitiva funktioner och skolrelaterade färdigheter inom läsning, skrivning och aritmetik. I Studie III undersöktes olika mått på arbetsminne, och deras prediktiva kapacitet i relation till matematisk förmåga mätt genom nationella prov i matematik, samt effekten av arbetsminnesträning på matematisk förmåga. I Studie IV undersöktes vilken roll arbetsminne och komplex exekutiv funktion har i identifiering av barn i behov av stöd i riskzon för matematiksvårigheter.

Resultaten från Studie I visade att utrednings- och stödinsatser kunde bidra till att förstärka ett brist-orienterat synsätt på barn i behov av stöd. I kontrast till detta, delgav lärare och föräldrar i Sverige att utredningar kunde hjälpa dem att förstå barnets behov på ett bättre sätt. Resultaten från studie II-IV visade att enbart den metakognitiva träningen, fokuserad på komplex exekutiv funktion, bidrog till förbättringar efter arbetsminnesträning. Resultatet indikerade också att arbetsminnesträning predicerar matematisk prestation i nationella prov i matematik, och att ett mer komplext arbetsminnesmått var en bättre prediktor än enklare arbetsminnesmått. Slutligen visade resultaten också att komplex exekutiv funktion i form av planeringsförmåga var en bättre prediktor än enkelt arbetsminnesmått vid utredning av risk för matematiksvårigheter.

Resultaten från studierna diskuterades i relation till syftet med utredning: att bidra med kunskaper vid utformande av extra anpassningar, särskilt stöd och undervisning för barn i behov av stöd. Eftersom komplex exekutiv funktion – planerings- och metakognitiv förmåga - verkar vara en viktig kognitiv funktion i lärandet, bör man ta hänsyn till detta både i utrednings- och stödinsatser kring barn i behov av stöd generellt, och särskilt kring barn i riskzon för matematiksvårigheter. Det belystes också att i stödinsatser är lärarens roll som mediator av metakognition och komplex exekutiv funktion viktig.

Nyckelord: Barn i behov av stöd, Utredning, Arbetsminne, Arbetsminnesträning, Komplex exekutiv funktion, Planering, Metakognition, Matematiksvårigheter.

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LIST OF PAPERS

This thesis is mainly based on the following four papers, herein referred to by their Roman numerals:

Study I Lebeer, J., Birta-Székely, N., Demeter, K., Bohács, K., Araujo Candeias, A., Sønnesyn, G., Partanen, P. & Dawson, L. (2012). Re-assessing the current assessment practice of children with Special Education Needs in Europe. *School Psychology International*, 33(1): 69-92.

Study II Partanen, P., Jansson, B., Lisspers, J., & Sundin, Ö. (2015). Metacognitive strategy training adds to the effects of working memory training in children with Special Educational Needs. *International Journal of Psychological Studies*, *7*(3), p130.

Study III Partanen, P., Jansson, B. & Sundin, Ö. (2015). Exploring the relation between working memory and national curriculum performance in mathematics in children with Special Educational Needs. *Manuscript submitted for publication.*

Study IV Partanen, P., Jansson, B. & Sundin, Ö. (2015). The role of working memory and complex executive function in assessment of risk for Mathematical Learning Difficulties in children with Special Educational Needs. *Manuscript submitted for publication.*

1. PREFACE

> "In time the mind comes to reflect on its own operations about the ideas got by sensation, and thereby stores itself with a set of ideas, which I call ideas of reflection…Thus the first capacity of human intellect is fitted to receive the impressions made on it, either through the senses by outward objects, or by its own operations when it reflects on them."
>
> (Locke 1689)

> ". . . if somebody knows something, then he knows that he knows it, and at the same time he knows that he knows that he knows"
>
> (Spinoza 1632–1677)

> "…And I can see, hear, smell, touch, taste
> And I've got one, two, three, four, five senses working overtime
> Trying to take this all in,
> I've got one, two, three, four, five senses working overtime
> Trying to taste the difference 'tween the lemons and limes
> The pain and the pleasure and the church bells softly chime..."
>
> (Senses Working Overtime, XTC)

Everyone has memories from school - good and bad - and everyone has an opinion about the state of school and what should be done. Parents have ideas about how teaching and learning should be organized for their kids. Me too. When I was a kid in primary school, I attended a bilingual class, and we got our education mainly in our mother tongue Finnish. I remember frequent lessons in Finnish grammar, struggling with the structure of language, mediated by our beloved teacher. At the same time we also worked with Swedish grammar. It was hard work to learn grammar. Two parallel systems for speaking, reading, writing and thinking emerged.

I remember that during a period I was occupied with figuring out which language to think in. I think that it was during those early years in primary school my fascination for thinking and language awoke. I became consciously aware of my own thinking and the role of language. It was a truly metacognitive experience, in retrospect. Later, during graduate studies in psychology I ran into Vygotskij, who elaborated precisely on these issues.

With Vygotskij followed Luria, who broadly established our understanding of how the brain *works* in these matters. Some years ago, when I red Luria's seminal book *The Working Brain*, I sometimes could hear a voice in my thinking: "There is nothing called *a* working memory, there is only a *working* memory." I had to figure out the meaning of this sentence.

After graduate studies I returned to school as a psychologist, and after some twenty years as a practitioner my private conceptions about learning have transformed to professional ones, based on my experiences from work with children with special educational needs, but also from sensible teachers, parents, special educators, psychologists and other professionals in the field. Lots of children are referred to school health and clinical services, and many hours of work is put into assessment and remediation. What is assessed needs to matter in remediation, and this still has to be proved. And, in the long run, we need to make school work for these children, in order to help these children to learn in school.

2. INTRODUCTION

We know that there is a strong mutual relationship between successful learning in school and good mental health (Gustafsson et al, 2010). We also know that school places a great deal of both formal and informal expectations on children from first to last grade. One can study the formal expectations in the national curriculum of the school system in most countries, including the Swedish (Skolverket, 2011). Besides a vast amount of core content in different school subjects, there are also a number of underlying abilities that children are expected to develop or handle in learning: skills in planning, reasoning, communication, social interaction, problem solving and metacognition, etcetera.

Let us take a quick look at some expectations in the Swedish national curriculum for the compulsory school, and specifically the syllabus for mathematics. Besides core content in mathematics, it explicitly states that pupils should also develop their abilities to:

- formulate and solve problems using mathematics and also assess selected strategies and methods,
- use and analyse mathematical concepts and their interrelationships,
- choose and use appropriate mathematical methods to perform calculations and solve routine tasks,
- apply and follow mathematical reasoning, and
- use mathematical forms of expression to discuss, reason and give an account of questions, calculations and conclusions.

(Skolverket, 2011)

From a psychological perspective it is striking that in the centre of these goals and expectations are clearly underlying abilities of planning, reasoning, attention, self-monitoring and awareness of strategies. Using psychological terms some of them could be termed executive functions, metacognitive abilities, self-regulatory skills etcetera. Also, from a sociocultural perspective, it is impossible not to associate to seminal neuropsychologist and early executive function researcher Alexander Luria (1979) who stated that these types of expectations form the cultural aspect in learning and development:

> *the "cultural" aspect --- involve[s] the socially structured ways in which society organizes the kinds of tasks that the growing child faces and the kinds of tools, both mental and physical, that the young child is provided to master those tasks.*

The executive functions and metacognitive abilities, which can be found to a varying degree in all different schools subjects in the curriculum, concern all children at all ages in the compulsory school. They are evident from first to last grade, and they also affect the grading since teachers evaluate to what extent children reach these goals. National curriculum assessments that are made at third, sixth and ninth grade in compulsory school in Sweden explicitly evaluates also these kinds of abilities in children.

Thus, the "cultural aspect" is organized into the school system and the tasks children meet during the school day. But, in Luria's words, are we organizing tasks and providing tools for children appropriately, so that they can master these challenges? And, how do we organize assessment and subsequent remediation for children with special educational needs, to support them in these areas? Given the strong relationship between successful learning and good mental health, we can assume that in the long run, unmet needs harm the mental health of children in school.

2.1. Assessment for children with special educational needs

When learning tasks do not work or children seem to lack the tools, and initial measures taken by teachers have not worked out well, some children are referred to special educational and school psychological services for assessment and remediation. Two key purposes of assessment in the Swedish school system are to identify special educational needs (SEN) and to inform teaching and learning. Within a broader context, assessment in inclusive school systems like the Swedish primarily aims at supporting these children to optimal learning and development and to succeed in the mainstream school environment. In more segregated school systems, however, assessment plays a major role in selection and exclusion to and placement in special schools or special educational facilities (Watkins, 2007).

Among children referred to assessment teachers commonly report problems with planning, attention and self-regulation. National studies based on self-reports from children in school also confirm that these kinds of problems are commonly perceived (Socialstyrelsen, 2012). A regular process of assessment undertaken by psychologists is that evaluations of the child's functioning in the learning environment and at home, and achievement in school subjects are carried out. The child is then assessed with cognitive and/or special educational tests, different forms of remediation are prescribed, and a report with advice to teachers is produced.

2.1.1 Definition of children with special educational needs

In accordance with the Swedish school law (Skollagen, 2010) the term "children with special educational needs" is not defined by any given property identified in the children, but defined functionally by the perceived needs of the child when he or she encounters the learning environment and the formal objectives for learning in school. Also, the term does not imply that the support given should be organized as special education, but primarily in the form of inclusive education in the mainstream school environment (i.e. adaptations and support given in connection with the regular classroom). However, neither does the term rule out re-occurring patterns in what these children struggle with that could be related to specific psychological processes. In this thesis we adhere to a functional definition of children with special educational needs, according to the above-mentioned legislation.

2.1.2 Two purposes of assessment for children with special educational needs

Assessment is an important part in the life of children with special educational needs who do not have a typical development or meet the formal and informal expectations for learning and development. The European Agency for Development in Special Needs Education (EADSNE) conducted a research project and agreed on a general description of assessment (Watkins, 2007):

> *Assessment refers to the ways teachers and other people involved in a pupil´s education systematically collect and then use information about that pupil's level of achievement and/or development in different areas of their educational experience (academic, behaviour and social)*

In particular, it was highlighted in the research that the purpose of assessment is different in different countries. Two main purposes were described; firstly, the purpose of identification of children with special educational needs in order to decide on additional resources for support for their learning, or placement in special educational facilities. Secondly, assessment may serve the purpose of informing teaching and learning, by highlighting strengths and weaknesses the child exhibits in different areas of their educational experience. Thus, assessment should increase the knowledge of the needs of the child.

When considering the first purpose of assessment, in many countries where inclusive education is not yet a right, access to regular schooling but also placement in special schools still depends on the results of cognitive, behavioural and learning tests. For children with special educational needs, this might constitute a barrier to inclusion and to access to a regular school environment.

There is a wide disparity between European countries in the prevalence of children with special educational needs. Finland, for example, reported 17.8% of children with special educational needs in 1999, whereas Belgium reported 5% and

Sweden only 2% (EADSNE, 2003). These numbers should be interpreted with some precaution however, since the legislations, definitions and procedures for identifying children with special education needs vary between countries.

Still, there are large differences among European countries in the proportion of children being schooled in separate special needs institutions. In Italy and Norway, it is a national policy to include all children with special educational needs, whatever their impairments. In the Swedish context, legislation in this area has moved in the inclusive direction, with the exception of special schools for children with intellectual disabilities or more severe sensory or multiple disabilities. In comparison, for example in Belgium, Romania, and Hungary, children with special educational needs are placed in special schools to a greater degree (EADSNE, 2003).

When considering the second purpose of assessment – to inform teaching and learning – three issues emerge regarding the methods of assessment of children with special educational needs. Firstly, since assessment needs to contribute to teaching and learning, the findings from assessment needs to be linked to curriculum objectives and school subjects more clearly. Secondly, assessment results also need to be linked to tools, approaches and remediations that are valid for and implemented in the child's individual educational plan (IEP). Thirdly and finally, assessment also needs to contribute information that helps the teacher to plan and adapt to the child's individual learning, and invite the child to active participation and inclusion in reflecting upon the child's own learning (Watkins, 2007). The second purpose of assessment, including these three issues is central in the inquiry of this thesis.

The EADSNE project, involving all Ministries of Education in the EU, concluded with recommendations on inclusive assessment and specified that:

> *. . . there is a need to develop systems of on-going, formative assessment that are effective for mainstream schools: giving schools and class teachers the tools to take responsibility for assessing the learning of all pupils including those with Special Educational Needs (SEN) and furthermore identifying (initially) the special needs of other pupils*

The term *formative assessment* in the quotation above refers to an assessment procedure where a child is invited to reflect on its own learning and to participate in an interactive feedback dialogue with the teacher. Formative assessment, in some contexts also called Assessment for Learning (AfL), in part originates from *dynamic assessment* (DA), originally a tradition of psychological assessment where the child’s potential level of cognitive functioning is activated through interactive, metacognitive feedback dialogues (Black & Wiliam, 2009).

Thus, assessment plays different roles depending on the purpose in the context of the school system in each country. In an inclusive school system the main purpose of assessment is not diagnostic, but rather to inform remediation, teaching and instruction for the benefit of children with special educational needs, corresponding to the second purpose described above.

When assessment and remediation aims at including a child in the regular school environment, a challenge becomes designing assessment and remediation that are perceived by teachers and parents (as well as the child itself) as supportive for the child’s needs and optimal learning. Assessment should help the teacher to adapt the teaching, but also involve the child in an interactive process where the child is jointly involved in reflecting on its own learning.

The second purpose of assessment described – to inform teaching and learning - creates some expectations regarding both the process of assessment leading to remediation, as well as instruments and procedures used during assessment. From the perspective of the assessment professionals, i.e. clinical and school psychologists (but also special educational teachers), the “tools of the trade”, in equal the assessment and remediation instruments, based on psychological constructs (for example intelligence, working memory, executive function, metacognition, etcetera) need to be valid in explaining and informing teaching and learning in the school domain.

To summarise, the thesis focuses primarily on the second purpose of assessment described above – how a number of psychological concepts used frequently in assessment inform teaching, learning and remediation, and increase the knowledge of the needs of the child. The thesis is concerned with children with special educational needs who are referred for assessment and remediation in general, but also with perceived problems in the areas of planning, self-regulation and attention in particular. Specifically, we explore the psychological concepts of working memory and complex executive function in psychological assessment and remediation in the school context, since these constitute major themes that are debated in school with regards to children with special educational needs. More specifically, the remediation studied in the thesis is working memory training, which has spread rapidly across a number of countries and is often applied during the school day. The thesis is also an exploration of remediation using two different training regimens - with and without metacognitive strategy training - and the effects on both cognitive functions and school related subjects. During the course of the studies conducted in the thesis, the intersection or overlapping of working memory and complex executive function came to be of particular interest, as well as the relation to mathematics in school. Let us therefore examine these concepts and methods more in detail.

2.2 Working memory and executive function

2.2.1 Working memory

There are a number of situations in everyday life where working memory is believed to play a crucial role, such as listening to instructions, solving a math problem, reading a text, and carrying out a plan. All these situations require the ability to retain and execute information.

The concept of "working memory" was termed by Miller and colleagues in the classic book *Plans and the Structure of Behavior* (Miller, Galanter & Pribram, 1960):

> *Without committing ourselves to any specific machinery, therefore, we should like to speak of the memory we use for the execution of our Plans as a kind of quick access, "working memory". There may be several Plans, or several parts of a single Plan, all stored in working memory at the same time. In particular, when one Plan is interrupted by the requirements of some other Plan, we must be able to remember the interrupted Plan in order to resume its execution when the opportunity arises. When a Plan has been transferred into the working memory we recognize the special status of its incompleted parts by calling them "intentions".*

As stated in the quotation, working memory originally referred to intentional and goal-directed behaviour, and the role of plans was central in this respect. Later developments in models of working memory did not elaborate upon or include the role of plans in all aspects.

For example, in the influential Baddeley (1986; 2007) model of working memory, the so-called *multicomponent model*, three components were originally described: a visuospatial and a phonological component responsible for temporary storage of short-term information, and a central executive responsible for more elaborate processing of information. Later, Baddeley added a fourth component to the model, the episodic buffer, which integrates information across domains, for example visual, spatial and verbal information. Working memory in this model thus refers to important cognitive processes involved in one's ability to retain information for a short period and use it after a delay (e.g., Baddeley, 1986, 2007).

Following a division of working memory into simpler components of temporary storage, and more complex components of elaborate processing, typical tasks have been developed to tap these processes, both in experimental studies and in development of assessment instruments. Simple working memory span tasks are for example digit span and spatial span included in psychometric batteries like the Wechsler tests (Wechsler, 1991; 2006). The digit span task requires the child to listen to a sequence of digits and then repeat the proper order, with increasing level of difficulty. In spatial span, the assessor taps out a sequence of block patterns on a three-dimensional plate consisting of ten blocks. The child is asked to repeat the sequence by pointing at blocks in the correct order, and the sequence is progressively increased in length, until the child reaches a threshold. Simple working memory span tasks consist of repeating the proper order in sequence without distractors. More complex working memory span tasks involve an addition of some kind of manipulation or distraction to the simple span tasks. This might be, for example, reporting the proper order backwards, or simultaneously conducting a second task.

In addition to *modality* differing in working memory tasks (e.g. auditory versus visual), the content of tasks also varies in terms of semantic complexity. In both digit and spatial span, the content of the tasks is relatively free from meaning (i.e sequences of digits and blocks) while in other working memory tasks like sentence span tasks (Daneman & Carpenter, 1980) where the child elaborates sentences of increasing length, semantic load and verbal comprehension is also assumed to play a role in working memory performance.

After Miller's introduction of the concept of working memory, a substantial amount of subsequent research has focused on the relation between simple temporary memory storage and more complex executive attention processes, in line with Baddeley's multicomponent model. In a review elaborating on the role of more simple and more complex working memory tasks, it was concluded that storage and more complex processing components in working memory are strongly related to one another, with both shared and unique variance attributed to them (Unsworth, Redick, Heitz, Broadway & Engle, 2009).

Some researchers have stressed other aspects of working memory and developed alternative models. For example, *the attentional control model* (Engle & Kane, 2004) argues that working memory capacity can primarily be explained by differences in executive attention. Another model, that is given particular emphasis in this thesis, is *the embedded process model* by Cowan (2012). This model advocates that working memory should be understood as embedded processes involving both long-term memory representations that are activated in tasks, and focus of attention that makes activated items in the long-term memory salient. In Cowan's model concepts of quite great complexity can be processed in working memory, provided that reasonable knowledge of these concepts has been integrated in long-term memory.

Following a more simple working memory span model, a teacher might consider reducing complexity of information for example in classroom instructions, in order not to overtax the working memory capacity. Instead, following Cowan's embedded process model, the teacher could aim to reduce complexity by teaching the child an appropriate concept that organizes the information, or hand over a more efficient strategy (Cowan, 2014). No matter which model is chosen, there is still a working memory capacity limit to consider in teaching and learning, and at a certain point the information to be processed is too complex or involves to many components to integrate, leading to cognitive overload. However, when considering Cowan's model, working memory capacity is not merely a question of number of stimuli or information to process simultaneously, but also a question of using and developing more complex information like goals, plans, concepts, strategies and previous knowledge in the service of working memory, in order to attend and stick to the task.

While the multicomponent model of Baddeley in part can be interpreted as focussing more on temporary storage and decay of stimuli in visuospatial and phonological working memory, a model like Cowan's, incorporating processing of complex information that can be attended from long-term memory, has consequences for both assessment and remediation of children with special educational needs. These issues will be further explored in the thesis.

2.2.2 Simple and complex executive function

In conjunction to the aforementioned working memory research, some have turned their attention to the central executive processes and executive function. As suggested by Miyake et al. (2000) in their classic paper, executive function is concerned with the inhibition, shifting and updating of the mental content and working memory, as a contrast to simpler working memory operations such as span and short-term storage.

Some authors propose a division of executive function as well, where *simple* executive function is concerned with executive aspects of attentional processes of sustaining, shifting attention and inhibition (Lehman, Naglieri, & Aquilino, 2009) while *complex* executive function requires more goal-oriented planning, strategy use, self-monitoring, updating and metacognitive ability (Best, Miller, & Naglieri, 2011). Das and Misra (2015) further elaborated along these lines on the umbrella concept of executive function and proposed that *planning* including problem solving together with working memory form executive function as separate, but interdependent processes.

Consequently, the early and original definitions of executive function (Luria, 1976; Das, 1980; Lezak, 1982) actually stress the capabilities of formulating goals, organizing behaviour, planning and carrying out plans, and self-monitoring. It is interesting to note that Miller's earlier cited original definition of working memory actually also involved the term "Plan", pointing to the complex interrelatedness between the concepts of working memory and executive function.

Later research has supported the validity of the division of attention and planning in executive function (Puhan, Das, & Naglieri, 2005; Lehman, Naglieri, & Aquilino, 2010; Best, Miller, & Naglieri, 2011). In this thesis we therefore adhere to a division of working memory as well as executive function in simple and complex processes in order to explore to what extent these inform assessment and remediation for children with special educational needs. In the context of this thesis, particular focus has been given to the concept of *planning* as a complex executive function.

2.2.3 Planning

Planning as an activity has face validity in the school context, since learning intuitively requires a great deal of planning. Besides developing and following lesson plans and Individual Education Plans (IEPs) for children with special educational needs, the very structure of the school day and work requires planning on the part of the child, as well as the teacher. Many teachers introduce work schedules, which children are required to follow, and the tasks in learning require varying amount of planning. For example, solving a mathematical problem in steps, or reading a text in order to answer questions or write a short report summarizing the main points requires planning. This is no least apparent when considering the curriculum syllabus described in the introduction from the perspective of planning.

However, planning is not only a sociocultural activity embedded in learning, but can also be seen as a psychological process, i.e. a complex executive function. Das and colleagues introduced planning as a central *neuropsychological* process as part of the Planning-Attention-Simultaneous-Successive (PASS) theory based on the theories of Vygotskij and Luria (Das 1980; Das, Kar & Parrila, 1996; Das; Naglieri & Kirby, 1994). In school context, Naglieri and Johnson (2000) showed that children with special educational needs with (neuropsychological) planning weaknesses could benefit from cognitive strategy instruction emphasizing planning with regards to mathematics. Research has also shown that planning facilitation improves mathematical skills in children with ADHD (Iseman & Naglieri, 2011).

Similarly, it has been proposed that during assessment overt verbalization helps children with poor planning ability to improve cognitive performance on complex tasks (Cormier, Carlson & Das, 1990). The role of feedback and verbalization during concurrent cognitive performance (for example during assessment or remediation), was in turn suggested by the authors to be linked to self-monitoring behaviour and *metacognition* (Carlson & Wiedl, 1992). Let us therefore turn our attention to this latter concept.

2.2.4 Metacognition

Metacognition is a related and overlapping concept to the above-mentioned complex executive function and planning processes. Metacognition, outlined by Flavell (1976) as *"one's knowledge concerning one's own cognitive processes or anything related to them"* has been related to executive function, self-regulation and learning strategies (Brown, 1987; Zimmerman, 1990). Flavell (1979) initially described four classes of phenomena related to metacognition: (a) metacognitive knowledge, (b) metacognitive experiences, (c) goals or tasks and (d) strategies or actions. In summary, metacognition refers to when a person deliberately plans, monitors and evaluates one's cognition involved in all types of activities, among them problem solving, learning activities etcetera.

The roots of the concept of metacognition can however be traced back to both ancient and later western philosophers like Socrates, Plato, Spinoza and Kant elaborating on the phenomena of the mind and self-awareness. In modern psychology Vygotskij, colleague of Luria, has been proposed as one of the early meta-cognitivists in developmental and educational psychology (Bråten, 1991; Fox & Riconscente, 2008). According to Vygotskij (1987), at the core of the concept of metacognition is the concept of *conscious awareness* in learning and development:

> *Conscious awareness is an act of consciousness whose object is the activity of consciousness itself.*

This simple definition in mind, together with Flavells' definition, explains metacognition as actively involving turning one's attention to the inner realms of one's thinking, cognitive processes and feelings, eventually resulting in conscious awareness.

In recent years metacognitive models have been applied in cognitive-behavioural therapy and mindfulness in clinical psychology (Wells, 2002; Jankowski & Holas, 2014). In an educational context researchers have studied how metacognition develops, what effects it can have on cognitive functioning and learning and how it can be enhanced through different types of structured interventions in school settings (Annevirta & Vauras, 2006; Cleary & Zimmermann, 2004; Georghiades, 2004; Hartman, 2001). It has been argued that metacognition supports a person to perform cognitive tasks more effectively (Metcalfe &

Shimamura, 1994). This latter argument has been a central starting point for exploration in this thesis.

Many of the educational models of metacognition consist of phases of problem solving, during which typical metacognitive behaviours are nurtured. For example, Davidson, Deuser and Sternberg (1994) proposed four metacognitive processes during problem solving: (1) identifying and defining the problem, (2) mentally representing the problem, (3) planning how to proceed, and (4) evaluating what you know about your performance. Kapa (2001) proposed a similar structure for the process phases in metacognitive support: (1) problem identification, (2) problem representation, (3) planning how to solve, (4) planning performance (including self-monitoring) and (5) evaluation. Thus, in the operationalization of metacognition in the context of education, the by-now familiar concept of planning recurs.

When summarizing the research on metacognition in an educational context, there is a clear move from a discussion of the general construct of metacognition to situated research in the outcomes of metacognition in education by training thinking skills and metacognitive strategies in order to enhance school performance (Georghiades, 2004). It is obvious when inspecting the research in the related fields of working memory, executive function, planning and metacognition that these are intertwined and overlapping concepts, and as such difficult to study separately, especially in complex environments like school (Hofmann, Friese, Schmeichel, & Baddeley, 2010). Next these concepts will be explored in relation to the research on children with special educational needs.

2.2.5 Working memory, complex executive function and children with special educational needs

In the school context working memory has been addressed as a crucial cognitive function, and it has been argued that working memory difficulties are underlying learning difficulties for children with special educational needs (Alloway, Gathercole, Adams & Willis, 2005). Previous research on the relation between working memory and school related abilities has shown that low working memory performance has negative consequences for the progress of reading, mathematics as well as language and reading comprehension (Passolunghi & Siegel, 2001; Signeuric, Ehrlich, Oakhill, & Yuill, 2000; Swanson, 1994; Swanson, Howard, & Sáez, 2006). Reversely, Pickering and Gathercole (2004) has also studied children with special educational needs and found that many of these children perform poorly on measures of complex memory, including working memory.

Studies have shown that children with special educational needs perform below expected levels of working memory and that low working memory is related to difficulties in both reading and mathematics (Alloway, Gathercole, Adams, & Willis, 2005). Regarding children with mathematical learning disabilities (MLD), it has been proposed that working memory is central in mathematical skill development in primary school children (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Also, studies suggest that both visuospatial and verbal/auditory working memory contribute to the development of mathematical skills and consequently working memory deficits contribute to mathematical learning difficulties (Alloway, Gathercole, Adams, & Willis, 2005; Passolunghi & Siegel, 2001; Raghubar, Barnes & Hecht, 2010; Swanson & Jerman, 2006; Wilson & Swanson 2001).

Previous studies have shown that working memory performance and attainments on national curriculum assessments in mathematics are strongly connected among primary school children (Gathercole, Pickering, Knight & Stegmann, 2004; Nyroos & Wiklund-Hörnqvist, 2012) as well as among low achieving children (Gathercole & Pickering, 2000). Thus, working memory capacity seems to be an important predictor of children's mathematical achievement in school and could therefore be used to identify children at risk of failing on national curriculum assessments and in the subject of mathematics.

Similarly, studies have suggested that executive function in general is related to mathematical achievement (Bull & Lee, 2014) and that complex executive function including planning is related to both math and reading achievement and that it is a domain-general ability predicting academic achievement (Best, Miller & Naglieri, 2011). In a recent study Cai, Georgiou, Wen and Das (2015) found that the complex executive function of planning accounted for unique variance in mathematics over and above the effects of both nonverbal cognitive ability and working memory.

2.2.6 Mathematics and mathematical learning disabilities

As described in the introduction, the excerpt from the curriculum and syllabus in mathematics reveals that mathematic learning in school requires development of complex executive function. Geary (2013) concluded in an overview of the current scientific debate that the early foundations for mathematics learning include learning a system of representing number magnitudes (quantities), as well as their relation to each other. Besides these two, a third system is stressed by Geary: the attention—control and problem solving system that enables the processing of mathematical thinking.

Both the concepts of working memory and executive function seem to add to the understanding of mathematical learning and possibly development of mathematical learning difficulties. There are a number of unresolved issues regarding the nature of mathematical learning and development, but regardless of these, the attention-control and problem solving system described by Geary seems to point to executive functions. In this thesis attention is given specifically to the contrast between simple working memory and the complex executive function of planning, strategy use, and metacognition.

2.2.7 Neuropsychological perspectives on working memory and executive function

From a neuropsychological perspective Luria (1976) described planning as one of the three functional units in the brain, associated with the functioning of the prefrontal cortex (PFC). Originally the principles of brain functioning were postulated by Vygotskij and later developed further by Luria. The executive functions were termed as higher mental functions (HMF) that work by operations of orientation within a task, planning, switching to other actions and inhibitory control (Akhutina & Pylaeva, 2011).

In the Vygotskij-Luria framework it is stressed that these higher mental functions (self-regulatory and executive functions) develop in a social context, and that the structure, organization and localization of these brain functions are systemic and dynamic. This means that in the development of brain functions, in a specific task involving certain demands, two (or more) areas of the brain might be excited and develop a tendency to work as a unified system, creating an intracortical function. Vygotskij and Luria argued that the underdevelopment of higher mental functions often played a central role in the gradual and cascading development of learning difficulties in children with special educational needs.

Remediation but also prevention for children with learning difficulties thus involved moving these executive functions into the external world, and changing them into external activities, by means of training reflection, memorization, checking and reviewing hypothesis in problem solving, etcetera. The remediation thus aimed at reorganization of the dynamic systemic brain functions, and in an intriguing way foreshadowed later research on cognitive plasticity and neuroplasticity (Akhutina & Pylaeva, 2011).

In recent cognitive neuroscience research D'Esposito and Postle (2015) report several state-of-the-art studies using fMRI showing that what is represented by the prefrontal cortex is higher-order information, such as task rules, goals or abstract representations. They suggest that the role of the prefrontal cortex is less focused on storage, and more on providing attentional control of long-term memory representations. This would suggest that Vygotskij's and Luria's original description of the role of the prefrontal cortex in planning is in line with the research reported by D'Esposito and Postle, as well as Cowan's embedded processes model.

There is a need to further investigate the specific role of simple working memory and more complex executive function in typically referred children with special educational needs, and particularly in development of learning difficulties including mathematical learning difficulties. If more simple working memory functions (span/storage/simple manipulations) predominantly predict mathematical learning, directing remediation to training of more simple working memory functions should be the way forward. If more complex executive function to a greater degree is involved in mathematical learning, including development of mathematical learning difficulties, both assessment and remediation should to a greater degree address and intervene on complex executive function.

In the light of the previously reported research on different models of working memory and executive functions (Baddeley, 1986, 2007; Luria, 1979; D'Esposito & Postle, 2015) there is delineation between processing of more simple stimuli versus more complex information, which also has consequences for assessment, remediation and eventually teaching and instruction. By including processing of more complex higher-order information like goals, plans and abstract rules, we need to broaden our perspective on the role of and relation between working memory and executive function in learning.

In the context of psychological assessment, the differences in models of working memory and executive functioning leads to some obvious questions: should we assess more simple or more complex working memory and executive functioning? What measures have validity in predicting learning and special educational needs? What conclusions can we draw from these assessments? What do they predict in school?

In addition, in the context of remediation, one of many questions that follows is: should we recommend regular working memory training, or working memory training boosting complex executive function by metacognitive strategy training? In the applied environment in school these are altogether important questions. A training regimen focusing on adaptive training of mainly simple working memory, by increasing the level of difficulty of working memory tasks, contrasted with a training regimen that enhances cognitive performance by adding training of complex executive function of planning and metacognition will require different designs of remediation in school. In the first, it is primarily a matter of compliance and persistence in sticking to the exercises, and possibly maximizing time on challenging tasks. In the second, it will also be a matter of developing goals, plans, strategies and self-monitoring – higher mental functions - during the training.

2.3 Working memory training and metacognitive strategy training

2.3.1 Working memory training

In this thesis, we used a working memory training program to study and contrast some of the abovementioned questions. The program used was Cogmed™ working memory training (Cogmed, 2009), (earlier termed Robomemo), an established and well-researched computer-based training program consisting of tasks designed as computer games, training different skills related to working memory (Klingberg, 2010). The tasks included are visuospatial and auditory working memory tasks embedded in computer games. The central principle of the tasks is that the child is presented with a sequence (for example of visual objects lighting up or phoneme segments read aloud) and asked to reproduce it via mouse-click on a subsequent display. Twelve of fourteen tasks are predominantly in visual modality. Tasks involve variations of forward and backward working memory processing and varying distractors or simple manipulations in the form of for example rotations of stimuli. Two tasks address auditory working memory in the form of letter/phoneme and number sequence identification. The program is adaptive and adjusts for the level of difficulty continuously during the training based on the child's progression. Thus the children are required to perform at the limit of their working memory capacity. For a more detailed account of the type of working memory tasks in the training program, see Klingberg, Forssberg and Westerberg (2002).

Several studies concerned with computer-based working memory training (including the Cogmed program) have shown a significant improvement on working memory in preschool and school children (Holmes, Gathercole, & Dunning, 2009; Morrison & Chein, 2010; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009). This has particularly been the case among children with ADHD (Holmes et al, 2010; Klingberg, Forssberg, & Westerberg, 2002). This kind of improvement of the actual cognitive function (for example working memory) trained is called near transfer, while far transfer is related to changes in a skill or ability that is not identical to the trained cognitive function (Barnett & Ceci, 2002). Research suggests that the effects following computer-based working memory training show far transfer to school related skills, such as mathematics and reading comprehension (Dahlin, 2010; Holmes et al., 2009). Thus, the research by Klingberg and colleagues is important and groundbreaking, since it showed that working memory is amenable to change, and supported the idea of neural and cognitive plasticity.

However, a meta-analysis (Melby-Lervåg & Hulme, 2012) has challenged the notion of the effectiveness of working memory training in general and its enhancing effect on cognitive functions in typically developing children. The authors concluded that working memory training seems to produce only short-term training effects. The effects do not sustain over time and do not show far transfer to subject areas. Other reviewers suggest that working memory training indeed shows far transfer to school subjects and academic achievement (Titz & Karbach, 2013) but that more research is needed in order to corroborate the results.

Given the mixed results, it has been proposed that further study in the field of cognitive training should not only investigate *whether* the training works or not, but should rather focus on what *training regimens* and conditions result in the best effects. However, in many studies of for example working memory training the conditions surrounding the training are not elaborated upon (Morrison & Chein, 2011). Furthermore, it has been suggested that individual differences in cognitive functioning among children with special educational needs should be taken into account when evaluating effects of cognitive training programs (Jaeggi, Buschkuehl, Jonides & Shah, 2011; von Bastian & Oberauer, 2014). These points are central in the inquiry of this thesis: a further investigation of the effects of different training regimens, and individual differences in cognitive functioning, particularly in working memory and complex executive function.

2.3.2 Cognitive and Metacognitive Strategy Training

According to Holmes et al. (2009), a majority of children being subject to working memory training reported that they had used a number of different strategies in order to improve the training. The authors concluded that "*training may indeed enhance attentional focus and stimulate a whole set of strategies that can be flexibly deployed with generalized benefits in a wide range of activities that place heavy demands on WM.*"

How these strategies can be operationalized, how they develop and can be systematically enhanced, and which effects they have on cognitive performance during computer-based training needs to be clarified. We also need to place the phenomena of strategy use in the theoretical context of working memory and complex executive function in order to explore the effects.

Studies have shown that strategy training by using rehearsal, imagery and semantic coding strategies has a positive effect on working memory performance (Caretti, Borella, & De Beni, 2007; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003). Related to this, research has also shown that working memory performance can be enhanced by metacognition. For example, Whitebread (1999) showed that the relationship between working memory capacity and cognitive performance was dependent upon metacognitive abilities. Also, Autin and Crozet (2012) demonstrated that by addressing children's metacognitive interpretation of a particular task, the working memory span improved.

The effects of metacognitive training among children with special educational needs have been examined in computer-based and regular learning environments, yielding positive effects on mathematical problem solving (Mevarech, 1999; Teong, 2003) and on general problem solving (Borkowski, Estrada, Milstead, & Hale, 1989). It has also been suggested (Passolunghi & Siegel, 2004) that problem solving performance is related to the ability to reduce the accessibility of irrelevant information in memory, and thereby increasing the possibility of retaining new information. Also, considering the aforementioned research on planning facilitation of children with special educational needs (Naglieri & Johnson, 2000; Iseman & Naglieri, 2011) cognitive strategy training was a central component in the remediation.

In this context, cognitive strategies could be viewed as domain or task specific strategies (e.g., elaboration, rehearsal and/or organization strategies) for dealing with the tasks at hand (Boer, Donker-Bergstra & Kostons, 2013). Metacognitive strategies consist of monitoring strategies used in the different phases of the learning – from planning a task to the execution of the task, and to summarization and evaluation after the completion of the task.

The metacognitive strategies can be seen as higher-order thinking strategies that involve planning, self-reflection, self-questioning and evaluation, leading to a formulation of metacognitive knowledge. A meta-analysis (Boer et al., 2013) has pointed out the importance of redirecting the child from using more domain-specific task-oriented cognitive strategies to using more metacognitive and self-regulatory strategies. Similarly it has been suggested that training metacognitive strategies is more effective than training fewer and/or simpler rule-based cognitive mnemonic strategies (Hattie, Biggs, & Purdie, 1996). Thus, when creating metacognitive training procedures, a broad range of not only cognitive strategies but also metacognitive strategies should be employed.

2.3.3 Design of Metacognitive Strategy Training

A number of researchers and practitioners in the field of *cognitive education* have developed principles and frameworks for what can be labelled as metacognitive training in educational settings. Metacognitive interventions in the form of structured guided interactions between the teacher and children are expected to create prerequisites for generalization and transfer from cognitive training to specific cognitive functions (for example working memory, executive function) and to general cognitive ability (Das, 1999; Das, Naglieri, & Kirby, 1994; Feuerstein, Rand, Hoffmann, & Miller, 1980, 2004; Tzuriel, Kaniel, Kanner, & Haywood, 1999).

With the rapid development of the use of information and communication technology (ICT) in education (i.e. computers, tablets, smartphones) especially in the Nordic countries (Wastiau et al, 2013), computerized cognitive training programs including the aforementioned working memory training have emerged the last decades, addressing a spectrum of both broader and narrower cognitive functions, for example general intelligence, working memory and executive functions (Bergman Nutley et al, 2011; Klingberg et al, 2002; Titz & Karbach, 2014). For children with special educational needs, remediation in school with support of ICT is a growing trend (Istenic Starcic & Bagon, 2014).

In the particular context of computer-based training programs applied in educational settings, the research regarding the specific role of the teacher in instructing, assisting and guiding the computer-based learning deserves some attention. Research by Kapa (2001) has suggested that metacognitive support handled by the adult in a computerized environment significantly improves problem solving performance in children. In several studies (Klein, 2000; Nir-Gal & Klein, 2004) it has been proposed that the teacher, by *mediating* the computer-based learning, has a facilitative role in both cognitive performance and learning. The concept of mediation was originally termed by Vygotskij (Vygotskij & Luria, 1994) and was part of the social aspect involved in development of the higher mental functions or executive functions, previously described. Feuerstein (1979) further developed this theory and termed it *mediated learning experience* (MLE):

> *Mediated learning experience is the interactional processes between the developing human organism and an experienced, intentioned adult who, by interposing himself between the child and external sources of stimulation, mediates the world to the child by framing, selecting, focusing, and feeding back environmental experiences in such a way as to produce in him appropriate learning sets and habits. (p.71)*

Building upon the concept of mediated learning, the previously mentioned interactive approach to assessment and remediation called dynamic assessment (DA) was developed. Dynamic assessment refers to an array of procedures where test performance (or learning performance) is examined before and after an intervention procedure in order to inform remediation and increase validity of assessment (Swanson & Lussier, 2001; Caffrey, Fuchs & Fuchs, 2008).

In the context of this thesis, research on dynamic assessment of working memory has shown that giving cues, prompting and guiding during assessment reveals additional information about the child's working memory functioning and its plasticity, with implications drawn for both assessment and remediation (Swanson, 2006). Also, the aforementioned research on the complex executive function of planning (Carlson & Wiedl, 1992) proposed that planning processes could be addressed with a dynamic assessment procedure, where the adult by giving feedback and stimulating the child to overt verbalization, helps the child to improve cognitive performance.

In this thesis, inspired by an interactional and formative approach, we *dynamized* the computer-based training conditions in the intervention study (II). This was also done in line with the recommendations for inclusive assessment and remediation (Watkins, 2007) where it was stressed that actively involving the child in reflection on its own learning during remediation, in a formative process, should be considered.

We developed a metacognitive strategy training regimen that takes into account the above-mentioned research on complex executive function, and the role of planning, metacognition, self-monitoring and strategy use in assessment and remediation of children with special educational needs. In the intervention, we provided adult mediation in semi-structured sessions between the regular computer-based working memory training sessions, following research-driven principles (see summary of Study II). A quasi-experimental design was chosen in the intervention study, since applying remediation in the complex environment of school and with children requires a certain amount of flexibility and adaptability to the circumstances. We believe that by conducting a study under naturalistic conditions we might actually increase the *ecological validity* of the research.

2.3.4 Ecological validity

The concept of ecological validity is worth some consideration. It was originally formulated by Bronfenbrenner (1979) who stated that too much of the study of child development depended on the study of children in strange circumstances for short periods of time, in contrast with the ecologies of their everyday lives.

In the assessment and remediation context ecological validity would firstly refer to what degree measures or tests of for example working memory and executive function resemble the cognitive demands in the everyday environment, in this case the school, as experienced by children with special educational needs. This type of ecological validity is called *verisimilitude*. Secondly, it would also refer to the degree to which the measures or tests empirically relate to measures of everyday functioning, called *veridicality* (Chayttor & Schmitter-Edgecombe, 2003).

From an educational point of view, these types of ecological validity are important, since they create a bridge from the test instruments used in assessment to the everyday functioning of children with special educational needs in school. Similarly, a school or clinical psychologist or special education teacher prescribing remediation for children with special educational needs is hardly guided in this work by studying experimental research on working memory and executive function solely. Rather, in order to gain *ecological validity* the situated research on effective interventions and training regimens applied in school constitutes an important and to some extent overlooked area of inquiry, at least in contrast to the vast amount of experimental research in the area of working memory and executive function. More studies of typically referred children with special educational needs in school are needed.

3. AIM

The thesis explores the role of different assessment tools and training regimens in assessment and remediation for children with special educational needs. Of particular concern is the notion that assessment should inform teaching, learning and remediation. In this matter, the thesis specifically explores the roles of working memory, complex executive function and metacognition in assessment and remediation for a group of children with special educational needs who are frequently referred to school psychological and special educational services, and to some extent also to clinical services.

A number of questions are of interest: When conducting assessments and prescribing remediation for children with special educational needs, what kind of assessment tools are used and what dilemmas and challenges occur? What is the actual performance of functioning in areas of working memory and complex executive function, but also in school related subjects like reading, writing and mathematics in children with special educational needs? When addressing working memory by computer-based working memory training, does it produce transfer to working memory and other domain-general cognitive functions, but also to domain-specific areas of reading, writing and mathematics? Regarding the role of training regimens guiding assessment and remediation/intervention, does working memory training using a metacognitive training regimen based on complex executive function affect the results? What is the capacity of different types of working memory measures to predict mathematics performance in school? How do working memory and complex executive function relate more specifically to perceived difficulties in the area of mathematics among children with special educational needs? What are the implications for assessment and remediation practices following these questions?

A starting point for the thesis in Study I was to explore the prevalence of different assessment and remediation practices among child and student health professionals in Europe, including Sweden, and dilemmas and challenges as perceived by assessment professionals, teachers and parents, in the work with children with special educational needs. In Study II, a metacognitive strategy training framework was developed as a training regimen, guided by research on planning, metacognition, strategy training, and dynamic assessment, and applied on working memory training. In this study, effects of working memory training were compared between the two training regimens, with and without structured metacognitive strategy training, and also the overall effect of working memory training on cognitive functioning and school related skills of reading, writing and arithmetics. In Study III, the relation between different types of measures of working memory and mathematics performance was explored, as well as the effects of working memory training on mathematics achievement in national curriculum assessments in school. Study IV explored the role of working memory and complex executive function (planning) in assessment and contrasted these in prediction of risk for mathematical learning difficulties (MLD) in children with special educational needs.

4. THE EMPIRICAL STUDIES

Four studies have been conducted. Study I was an empirical study conducted as a part of a bigger cross-cultural European project called "DAFFODIL", aiming at improving assessment and remediation procedures of children with special educational needs. Studies II-III were quasi-experimental studies conducted in school. Study IV was an empirical study of data from school and special educational services.

4.1 General methods

In this section the general methods used in the four studies will be presented. However, these will be presented separately since the general methods, participants and measurements differ between the studies.

4.1.1 Participants and definitions of special educational needs and mathematical learning difficulties

In Study I, assessment specialists at school psychological services, clinical hospital departments, teachers and parents across seven countries participated. In studies II-III, special education teachers and children with special educational needs participated and in Study IV data from assessments by psychologists assessing children with special educational needs was analysed.

In the studies the term "children with special educational needs" refers to the needs of the child as perceived and identified by the assessment specialists, i.e. psychologists and special education teachers or other assessment professionals. This definition is not a clinical diagnostic category but based on a functional analysis according to Swedish legislation (Skollagen, 2010) in the parts that describe data from Sweden. The definition in the Swedish context thus approaches functional systems for assessment incorporating contextual aspects, for example ICF - International Classification of Functioning (World Health Organization, 2001).

Similarly, in Study IV, the term "Mathematical Learning Difficulty" does not refer to a diagnosed disability but a functional difficulty with mathematical learning based on the evaluation by professionals in school. This is important to stress since the formal diagnosis of mathematical learning disability has also been studied with different diagnostic criteria and measures and lacks coherent definitions (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007).

4.1.2 Measurement

In Study I questionnaires, semi-structured interviews and focus groups were used to gather data from assessment professionals, teachers and parents. Separate versions of questionnaires were developed with individual adaptations to each participating country in the study. Due to the poor response rates from teachers and parents, semi-structured interviews were chosen as the main data source for analysis for these groups of participants.

In Study II standardized psychometric measures on the children's performances both in cognitive and school related abilities were used. General cognitive nonverbal reasoning ability was measured with Ravens Coloured Progressive Matrices (Raven, 1995) and Block design from WISC-III (Wechsler, 1991). Auditory working memory was measured with digit span (Wechsler, 1991), including measures on forward processing (simple span) and backward processing (manipulation). Visuospatial working memory was measured with the spatial span test (Wechsler, 2006), similarly with measures on forward and backward processing. Arithmetic ability was measured using the Arithmetics test from WISC-III (Wechsler, 1991) which consists of arithmetic problems similar to those encountered in elementary math courses. Reading and writing skills were measured with DLS [Diagnostics of reading and writing abilities], a Swedish norm-referenced screening instrument of reading and writing abilities. DLS consists of four subtests measuring reading comprehension, phonological ability, word comprehension and spelling ability (Järpsten & Taube, 1997). These data were gathered at baseline, post-intervention and at 6-month follow-up. A standardized composite measure of working memory performance during working memory training was also calculated by the computer-based training program (Cogmed, 2009) at the start of the training (Training Index time 1) and the maximum working memory performance at the end of the training period (Training Index time 2).

In Study III the abovementioned auditory and visuospatial working memory measures at baseline were used, as well as Training Index at time 1 and 2. In addition, six subtests from the national curriculum assessment in mathematics in Sweden for third grade were used (Skolverket, 2010). The six maths subtests were: *Written arithmetic*, *Mental arithmetic*, *Time concepts*, *Numeric understanding*, *Fraction*: and *Area and volume*. An aggregate score was also calculated for the mathematical total sum from the six maths subtests. The maths scores are reported as raw scores, and treated as continuous, interval scale measures (Nyroos & Wiklund-Hörnqvist, 2012). A comprehensive description of the maths tests can be found in Study III.

In Study IV the Working Memory index drawn from WISC-IV was used as a measure of working memory. The Working Memory index consists of the subtests Digit Span, Letter-Number Sequencing and Arithmetics tapping short-term and working memory span, mental manipulation and phonological working memory (Leffard et al, 2010; Wechsler, 2003). The Planning index was drawn from the Cognitive Assessment System (CAS) to measure complex executive function. The Planning index subtests consist of three complex executive function subtests: Matching Numbers, Planned Codes and Planned Connections, that require planning, self-monitoring and metacognitive ability (Best, Miller, & Naglieri, 2011; Naglieri & Das, 1997). A dichotomous variable of at-risk or not-at-risk for mathematical learning difficulties (MLD) was measured by the assessing psychologists evaluating the children with special educational needs.

4.2 Brief summary of studies

This section will present a brief summary of the studies and the most relevant analyses and results.

4.2.1 Study I

Lebeer, J., Birta-Székely, N., Demeter, K., Bohács, K., Araujo Candeias, A., Sønnesyn, G., Partanen, P. & Dawson, L. (2012). Re-assessing the current assessment practice of children with special education needs in Europe. *School Psychology International*, 33(1): 69-92.

Background and aim. Assessment is an important part in the life of a child who does not have a 'typical development' or meet the expectations for learning and development in the school system. The European Agency for Development in Special Needs Education (EADSNE), conducted a research project and subsequently issued recommendations that specified that there is a need to develop systems of on-going, formative assessment that are effective for mainstream schools: giving schools and class teachers the tools to take responsibility for assessing the learning of all pupils including those with Special Educational Needs (SEN) and furthermore (initially) identifying the special needs of other pupils (Watkins, 2007).

This study explored the current assessment practices in a number of European countries (Norway, Sweden, Portugal, Belgium, Romania, Hungary and the British Virgin Islands), and the prevalence of static and dynamic assessment tools and practices among professionals working with children with special educational needs. The study also explored how assessment professionals, teachers and parents perceived the assessment practices and following remediation, and delineated a framework for important aspects that should be taken into account when designing assessment and remediation.

Method and analysis. A multi-modality research with online and hard copy questionnaires, telephone interviews, face-to-face semi-structured interviews and focus group discussions with assessment professionals (N = 166), teachers and parents (N = 25) were conducted in the seven partner countries. Only a few teachers completed the questionnaire and thus follow-up interviews were made by telephone or face-to-face. The main questions of the data gathering were: Who carries out assessment? What kind of settings, time, batteries and instruments are used for assessment? Are observations of classroom, home and context standard practice? What main difficulties are experienced, what is the general level of satisfaction, and what is the effect of assessment on children with regard to inclusion/exclusion and learning programming? Simple quantitative descriptive statistics were created from the questionnaires regarding use of assessment instruments. Qualitative analysis was used to identify reoccurring themes in interviews and focus groups by coding transcripts.

Results and conclusions. There was a wide disparity regarding what institutions and which professionals were involved in assessment of children with special educational needs across the seven partner countries, but in all countries both clinical, hospital and school/educational assessment professionals conducted assessment. In Norway, Sweden, Belgium and Portugal there was a tendency towards a transition to a child-centred and contextual assessment practice and a more active parental role in assessment, while a deficiency-oriented practice with a passive role for parents was dominant in Hungary, Romania and the Virgin Islands.

Regarding what test and instruments were used in assessment, the Wechsler scales were number 1 for assessing intelligence, far exceeding all the others. Similarly, the Child Behaviour Checklist (CBCL) for evaluating behaviour was high on the list. Other batteries widely used were the Kaufman ABC; the Peabody language tests, and tests for autistic functioning. Different countries used different batteries for school achievement, which are language dependent. Standardized developmental scales were also universally used, depending on local norm references. Dynamic assessment procedures, focusing on plasticity and potential level of functioning were rare in all countries.

Regarding assessment professionals experiences, satisfaction with test procedures varied greatly from country to country, depending mostly on the availability of resources. In Norway, Sweden, Belgium and Portugal there was a general satisfaction among professionals with the test procedures. Assessors however unanimously reported across countries that time, financial, and human resources constraints were the most significant problems experienced when evaluating children with special educational needs.

Teachers admitted that assessment reports helped them to better understand learners' problems, and adapt their teaching to activate children's learning. However, on the whole, they were less enthusiastic about the quality of evaluation than the assessment professionals. Again lack of time, financial and human resources were mentioned as the most important obstacles for the teachers' work with children with special educational needs. It seems that these three parameters represent a big gap between regulations, professionalism of the assessors, the knowledge and the possibility of taking action towards inclusion. These attitudes may also result from a more general view that assessment is a secondary, administrative, periodical action that precedes the main roles of the specialist. A suggestion of this type is corroborated by other studies that have shown that prevention and school-based treatment are the roles that US school psychologists see as most appropriate (Miller & Jome, 2010).

Parents reported mixed results across countries. Portuguese and Swedish parents had the highest rates of satisfaction with assessment experiences, to a substantial degree reporting that they had learned new things about their child's way of learning and needs. Dissatisfaction in all countries was linked to issues regarding the need to fight for their child's rights and to push the school into action, lack of resources and of useful recommendations.

In conclusion, the results point to the need for further development of the current assessment practices and to the linking of assessment to remediation/intervention procedures. Assessment procedures need to be adapted to include information on both a child's actual and potential functioning in order to promote inclusive education, and meaningful recommendations focusing on the need of the child rather than the dysfunctions. It should be formulated in an optimistic way, giving clear indications as to the construction of an academically and socially challenging individual educational programme for children with special educational needs.

4.2.2 Study II

Partanen, P., Jansson, B., Lisspers, J., & Sundin, Ö. (2015). Metacognitive Strategy Training Adds to the Effects of Working Memory Training in Children with Special Educational Needs. *International Journal of Psychological Studies*, *7*(3), p130.

Aim. The aim of Study II was twofold: Firstly, investigating the profiles of general cognitive ability, arithmetic ability, reading/writing skills and especially the variability of working memory functioning among a typical referred sample of children with special educational needs. Of particular interest was the prevalence of low performance in the different domains, and especially in the area of working memory. Secondly we wanted to examine the effects of computer-based working memory training (Cogmed) on both cognitive functions (working memory, general cognitive ability) and the school related skills reading, writing and arithmetics. Two training conditions were used during the working memory training: a regular and a metacognitive strategy-training regimen.

Method and analysis. Sixty-four primary-school children with special educational needs at ten schools participated in the study. The children of the respective schools were randomized into either an active working memory-training group or a control group and the schools participating in the study were randomized into one of two different training conditions. At five of the schools the participating children received regular working memory training and at the remaining five schools the children received working memory training with the addition of metacognitive strategy training. All children participated in the regular working memory training program consisting of daily sessions (approx. 45 min) for 25 consecutive schooldays, in a small group setting, sitting individually at computers with headphones.

The metacognitive strategy training was conducted in a small group setting, led by special education teachers, three times a week, in connection to the working memory training. The metacognitive strategy training sessions were semi-structured and involved the children engaged in teacher-mediated small group reflections, according to five principal areas developed from previous research on complex executive function, planning and metacognition: 1. *Labelling*. 2. *Goal-formulation*. 3. Reflections on *Cognitive strategies* 4. Reflections on *Metacognitive strategies* and 5. Reflections on *Transfer*.

Measures of general cognitive ability, auditory and visuospatial working memory, arithmetic ability, and reading and writing skills were gathered and analysed at pre-intervention, post-intervention and 6-month follow-up. Statistical analysis was conducted using cut-off scores for low performance, one-sample t-tests and likelihood ratios were used to compare the sample of children with special educational needs with a standardized normal population sample, ANCOVAs were used to compare children with low working memory with normal working memory on the different measures. Finally multiple ANCOVAs were conducted on post-intervention and 6-month follow-up data, controlling for pre-intervention levels in the respective cognitive and school related measures. Post-hoc tests were used to determine significant differences between the three groups: regular working memory training, working memory training with metacognitive strategy training and the control group.

Results and conclusions. When inspecting the performances of this typical referred sample of children with special educational needs, they performed significantly lower on the auditory working memory task compared to a normal age relevant population. Furthermore the group showed significantly lower ability on arithmetics as well as on all four measures of reading and writing. There were large effect sizes for word comprehension, arithmetics, spelling ability, phonological ability and reading comprehension, ranging from 0.82 to 1.65 standard deviations below the average expected levels for age.

In contrast to the auditory working memory performance, no significant differences were found between the referred sample of children with special educational needs and normal population on visuospatial working memory tasks. In the areas of general cognitive and problem solving ability the group of children with special educational needs performed at levels close to the population mean. No significant differences were found and effect sizes were negligible.

When inspecting the likelihood ratios the children with special educational needs were 4.22 times more likely to obtain low scores on auditory working memory, and 4.67 times more likely to have low arithmetics scores. On the reading and writing skills measures the incidence of low performance ranged from 3.27 to 6.09 times higher than in a standardized normal population sample.

Results from the working memory training showed a significant difference in working memory performance during training in favour of the metacognitive strategy training intervention. Furthermore, transfer effects occurred on visuospatial working memory measures at posttest and at 6-month follow-up. Post-hoc tests showed that the effects pertained only to the metacognitive strategy training intervention. No transfer to general cognitive ability, arithmetic or reading and writing skills occurred after training in the two training conditions.

It was concluded that since the children with special educational needs exhibited low auditory working memory, and the effects pertained to visuospatial working memory, the working memory profiles should be taken into consideration to a greater degree before referring children to working memory training. The children with special educational needs exhibited low performance in reading and writing skills, although this was not related to low working memory performance, while arithmetic skills were actually lower among children with low working memory performance compared to children with normal working memory. This suggests that the school-related skill of mathematics is of interest in the context of working memory training. It was also concluded that the metacognitive strategy training condition is important in optimizing performance in working memory training, and that such factors should be taken into consideration when designing interventions for children with special educational needs. More specifically this suggests that complex executive function and metacognitive and planning strategies should be addressed in working memory training, in contrast to relying merely on adaptive training of more simple working memory span and simple manipulations of working memory content. Another conclusion drawn was that far transfer from working memory training to school-related skills of reading, writing and arithmetic did not occur as an effect of working memory training in any of the conditions.

4.2.3 Study III

Partanen, P., Jansson, B. & Sundin, Ö. (2015). Exploring the relation between working memory and national curriculum performance in mathematics in children with Special Educational Needs. *Submitted manuscript.*

Aim. The aim of Study III was to examine the contribution of different working memory measures in predicting performance on the national curriculum assessment in mathematics in Sweden in a sample of children with special educational needs in third grade, and specifically analyse the effects of working memory training on mathematical achievement six months after finished training. Of specific interest was the role of pre-intervention working memory measures in predicting mathematics performance. Also, we were interested in how a change measure (post-intervention controlling for pre-intervention levels) could predict mathematical achievement, given the research on the role of dynamic assessment measures in assessment of working memory and cognitive functions (Swanson & Lussier, 2001; Caffrey, Fuchs & Fuchs, 2008). More specifically a hypothesis in this study was that a working memory performance measure accounting for change over time would be a stronger predictor of mathematical performance than static baseline measures of working memory.

Given the results from the previous Study II, indicating a significant relation between low performance in arithmetic and low working memory in children with special educational needs, a further inquiry into the relation between working memory and mathematics was justified. Also, given previous reviews of working memory training suggesting only limited and short term effects (Melby-Lervåg & Hulme, 2012), a follow-up on mathematical achievement after working memory training was important in order to examine possible far transfer effects in domains not measured in Study II.

Method and analysis. Eighteen children with special educational needs in third grade participated in the study and underwent computer-based working memory training (Cogmed, 2009). The children included were recruited from the two training conditions in Study II. Independent t-tests showed no significant differences between the conditions on working memory measures, and the groups were treated as one group in the analysis. The national curriculum assessment data from six different subareas in mathematics, including a total maths score, was gathered approximately six months after the working memory training. Measures of auditory and visuospatial working memory were gathered before the working memory training. Also, two direct working memory training performance composite measures were included - an initial baseline measure gathered in the beginning of the training, and a maximum working memory training performance measure gathered at the end of the training. Pearson correlations were conducted in order to examine the association between the different measures. Furthermore hierarchical multiple regression analyses were performed to determine the unique contribution of variance of the working memory measures on mathematical performance in each of the six subtests of maths as well as the maths total score.

Results and conclusions. After accounting for the effect of auditory working memory and initial baseline working memory training performance the results from hierarchical multiple regressions showed that the maximum working memory training performance measure was highly predictive of overall mathematical achievement and achievements in four out of six mathematical subtests. Furthermore, auditory working memory and initial baseline working memory training performance measures did not predict overall mathematical achievement or performance in any of the six subtests of mathematics. The strong predictive capacity of the maximum working memory training performance measure can be interpreted as a more complex measure of performance, tapping more complex executive functioning. The results could thus tentatively be interpreted to support research suggesting a role for more complex executive function in academic performance including mathematical achievement (Best, Miller & Naglieri, 2011; Cai, Georgiou, Wen & Das, 2015).

We conclude that changes in performance after working memory training are strongly related to mathematical performance in school in children with special educational needs, suggesting far transfer from working memory training to mathematics in school. We also suggest that there is a need to use more dynamic and complex working memory and executive function measures in predicting mathematical achievement for children with special educational needs. Specifically, the results challenge the benefits of relying on more simple working memory measures in predicting mathematical achievement in assessment practices of clinical and school psychologists.

4.2.4 Study IV

Partanen, P., Jansson, B. & Sundin, Ö. (2015). The role of working memory and complex executive function in assessment of risk for Mathematical Learning Difficulties in children with Special Educational Needs. *Submitted manuscript.*

Aim. The aim of Study IV was to explore the cognitive characteristics with regard to working memory and complex executive function in children with special educational needs at risk and not at risk for mathematical learning difficulties (MLD). We also wanted to examine the predictive role of working memory and complex executive function in mathematics learning difficulties as measured by the Working Memory index of WISC-IV and the Planning index of CAS.

Given the results from Study II, suggesting that incorporating metacognitive components that involve planning, goal-setting, self-monitoring and metacognitive strategy training optimizes the effects of working memory training, and the results from Study III suggesting that complex executive function to a greater degree than simple working memory is involved in mathematical achievement of children with special educational needs, we wanted to examine the respective role of simple working memory functioning and complex executive function in predicting the risk for mathematical learning difficulties. Specifically, we hypothesized that both the Working Memory and Planning indices should contribute to prediction of risk for mathematical learning difficulties, but that complex executive function as measured by Planning index should do this to a greater degree than the Working Memory index.

Method and analysis. Data from assessments of sixty-five children with special educational needs between the ages of 6 and 16 years that were referred to local school psychological services for assessment were included. Based on descriptions from teachers and/or special education teachers, psychologists made a classification of the specific area of difficulties that constituted reason for referral, in this case mathematical learning difficulties (MLD). Independent t-tests were conducted on Working Memory and Planning measures in order to determine if the mean scores differed significantly between the MLD and non-MLD group. A Pearson correlation was also conducted in order to examine the association between Working Memory and Planning indices. Furthermore two logistic regression analyses were performed to examine the unique contribution of working memory and planning on risk for MLD, entering one variable at the first step and the other variable at the second step, and finally reversing the entry.

Results and conclusions. Results showed that special educational needs children's performance on both Working Memory and Planning indices was significantly lower than the standardized population mean, and also substantially below the cutoff criterion for low performance. However, when MLD and non-MLD children were compared, while planning scores significantly differed between groups, the working memory scores failed to reach significance. The correlational analysis showed that there was a moderate positive correlation between working memory and planning.

Furthermore, the logistic regression analyses showed that only complex executive function (as measured by Planning) predicted risk for mathematical learning difficulties in children with special educational needs. The non-significant contribution of working memory was a surprising outcome considering research on the general role of both simple working memory storage and more complex working memory in cognitive functioning (Unsworth et al, 2009), but was in line with research which emphasizes the role of executive functions as well as complex executive function in learning, maths achievement and mathematical learning difficulties (Toll, Van der Ven, Kroesbergen, & Van Luit, 2011; Best, Miller, & Naglieri, 2011; Bull & Lee, 2014).

We conclude that the result from Study IV suggests that the early and original definitions of executive functions (Luria, 1976; Das, 1980; Lezak, 1982), stressing the capacities of formulating goals, organizing behaviour, planning, carrying out plans, and self-monitoring, are important dimensions in assessment and an integral part of the broad executive function concept. The results also support later research (Best, Miller & Naglieri, 2011; Cai, Georgiou, Wen & Das, 2015) stressing the role of complex executive function in academic achievement and learning in mathematics.

The results of our study also have consequences for the assessment practices of clinical and school psychologists, and it is strongly recommended to tap complex executive function when conducting a general cognitive assessment at an early stage in referrals of children with special educational needs, especially when screening for the risk for mathematical learning difficulties.

5. GENERAL DISCUSSION

The overarching aim of the thesis was an exploration of assessment and remediation practices of children with special educational needs. Specifically, the thesis explored the roles of working memory, complex executive function and a metacognitive strategy training regimen applied in working memory training, and the effects on cognitive functions and school related subjects in children with special educational needs. With regards to school subjects, effects on reading, writing and mathematics were examined in general, and the role of more simple working memory and complex executive function in predicting risk for mathematical learning difficulties was studied in particular.

5.1 Assessment and remediation dilemmas

The broad scope of Study I on assessment and remediation practices and perceived challenges among professionals, parents and teachers highlighted a number of urgent themes to discuss. These themes are considered in relation to the two purposes of assessment that were described in the introduction (Watkins, 2007) firstly, the purpose of identification of children with special educational needs in order to decide on additional resources and/or placement in special educational facilities, and secondly, the purpose of informing teaching and learning, by highlighting the strengths and weaknesses the child exhibits in different areas of their educational experience, in order to increase knowledge of the needs of the child.

A theme that emerged was that assessment in some contexts and countries in the study mainly reinforced a deficiency-oriented outlook on children with special educational needs, and that the main purpose of assessment was to obtain financial benefits or special educational resources, corresponding to the first purpose. These types of purposes function as gatekeepers for support, and assessment could thus become an obstacle in obtaining support, or even a tool for exclusion, which was the case in some countries.

Following the deficiency-oriented theme, parents, but also some assessment professionals reported that the assessment or test reports given at the end of the assessments were pessimistic, negative or mainly focusing on dysfunction and the weaknesses in the child. This is especially alarming in the light of social, cognitive and neuroscience research on self-theories (Dweck, 2000; Mangels, Butterfield, Lamb, Good & Dweck, 2006), suggesting that teachers and parents that foster an entity theory (intelligence is fixed) in contrast to an incremental theory (intelligence is malleable) lower their expectations on children's abilities, and that these children in turn also report lower motivation and expectations on their abilities in learning. Thus the outlook of reports, and the feedback given from assessment professionals to parents, teachers and children are of outmost importance, since these could influence their beliefs about intelligence and learning ability negatively. This in turn could counteract the purpose of assessment of increasing the knowledge of the needs of the child.

However, as a contrast, parents as well as teachers in some countries, including Sweden, also reported satisfaction with experiences of assessment and subsequent remediation. In these cases the assessment reports helped teachers to better understand learners' problems and adapt their teaching accordingly. Some parents similarly reported that they had learned new things about their child's needs and way of learning. These types of positive experiences correspond to the earlier described second purpose of assessment - to inform remediation, teaching and instruction by increasing knowledge of teachers and caregivers - and can be interpreted in line with the legislation for children with special educational needs in Sweden, stressing the importance of meeting the needs of the child in the inclusive mainstream environment in school (Skollagen, 2010). These experiences also highlight the necessity of linking assessment to remediation: without subsequent remediation assessment fails to contribute to a better understanding of the needs of the child, and adaptions of the teaching in the learning environment.

In the context of working memory and executive functions, it should be noted that instruments assessing general cognitive ability (in equal Wechsler) were the most frequently used, as reported in Study I, while specific assessment of working memory and executive functions were rarely reported. This was also the case with dynamic and formative assessment that incorporates interactive, metacognitive and strategy components as part of the assessment procedure. However, in recent years, since Study I was conducted, there has been a rapid development in research and assessment in these fields and a somewhat different picture might emerge today, when it comes to the use of more complex working memory and executive function measures in assessment. It can, however, be expected that static assessment of general cognitive ability still hold its major position in psychological assessment. Also, formative assessment is increasingly discussed among teachers, but to a lesser degree among assessment professionals regarding children with special educational needs.

Following the results from Study I, the results from studies II-IV can be discussed in relation to the initially explored purpose of assessment to inform remediation, teaching and instruction, and particularly the three issues earlier described: Firstly, how are working memory and complex executive function in children with special educational needs related to curriculum goals and school subject performances? This also involves discussing the concepts of working memory and complex executive function and their relation to each other. Secondly, regarding assessment tools and remediation, are assessment of working memory and complex executive function valid tools, and is working memory training including different training conditions a valid remediation for children with special educational needs? Thirdly, regarding a metacognitive strategy training remediation addressing complex executive function, mediated by the teacher, does it produce effects and help the teacher to adapt the child's learning by mediating complex executive function processes? In the following sections these issues will be discussed.

5.2 Working memory in children with special educational needs

With regards to working memory, the majority of children with special educational needs that were referred by the schools to working memory training in Study II did not exhibit clinically low levels of working memory performance. Furthermore it is interesting to note that the group as a whole only exhibited lower performance than normal population in auditory working memory, but not in visuospatial working memory or in general cognitive ability. This is in contrast to previous research (Alloway et al., 2005) that reported significantly lower visuospatial working memory in groups of children with special educational needs.

In addition, when inspecting the school related skills of reading, writing and arithmetic, it is clear that the referred group of children were challenged in all these areas to a substantial degree. However, only performance in arithmetic was specifically related to low performance in working memory. In the context of this thesis, arithmetic, and the broader domain of mathematics in school thus required further inquiry in order to understand the role of working memory in learning, which was elaborated in Study III.

There could be a problem with too broad inclusion criteria when referring children with special educational needs to working memory training in school. In our study we followed commonly recommended inclusion criteria for working memory training, based on behavioural observations of perceived problems with planning, attention and working memory, made in school by teachers and special education teachers. Thus, it could be argued that all children with special educational needs that exhibit difficulties in these areas, as observed in school, actually do not show low performance in working memory.

The reason for this could be that learning difficulties in school subject areas (reading, writing and arithmetic) could be interpreted as problems with planning, attention and working memory. The association could also be mediated by challenging or inattentive behaviours that are interpreted as problems with working memory. Tentatively this could also explain why this referred sample of children with special educational needs differed from other studies of working memory profiles of children with special educational needs (Alloway et al., 2005).

Following this, since the majority of the referred group of children with special educational needs in Study II did not actually show clinically low levels of working memory it could be argued that the referral and screening process to working memory training should be scrutinized to a greater extent when using working memory training as remediation in school. More research on the characteristics of typical samples of children with special educational needs referred to working memory training is needed.

The working memory profiles of the children with special educational needs from Study II could also be interpreted as mainly profiles of simple working memory (span and storage) and only to some degree more complex working memory (processing), but definitely not more complex executive function (planning and metacognition). Since we argue that the metacognitive strategy training addresses the latter, the results from Study II required us to broaden our inquiry further into the domain of complex executive function, which was done in Study IV. Also, there is an intriguing relation between working memory performance and performance in arithmetic in the results of Study II, which was further explored in Study III.

5.3 Effects of working memory training and metacognitive strategy training

A major finding in Study II was that working memory training with the addition of metacognitive strategy training intervention had lasting effects on visuospatial working memory, while no effects were found following the regular working memory training. These results were evident also when we compared changes in the training indices (measures of direct online working memory training performance) between the two experimental conditions over time. This strengthens the hypothesis that the metacognitive strategy training condition affected performance during working memory training. But what components in detail are responsible for the effects needs to be elaborated further in future research.

The results were restricted to visuospatial working memory, and forward processing in particular. In line with the terminology in this thesis, this could be considered to reflect a simple working memory span-storage component rather than more complex working memory or executive processes. By the addition of metacognitive strategy training we intended to boost the children's use of more complex executive function (organization, goal-direction, planning and metacognitive strategy use) in the working memory training. The results tentatively imply that even when training simple cognitive working memory span more complex cognitive and metacognitive executive higher order processes should be addressed. The results can also be discussed in relation to Cowan's embedded process model, as elaborated by D'Esposito and Postle (2015), where goals, plans, strategies and rules, in equal abstract representations can also be processed as part of the executive function process of the prefrontal cortex. Thus more complex executive function could affect more simple working memory performance, tentatively proposing a bi-directionality in these processes. This also fits the conclusions of Unsworth et al. (2009) pointing to the close interdependence between simple working memory storage and executive processes.

Consequently, it also points to Luria's (1979) as well as Lezak's (1982) original definitions of executive function, which suggested the possibility of processing more elaborate representations like goals and plans, and as operationalized in the concept of planning by Das (1980). Finally, it also tentatively supports a conclusion that teacher mediation of complex executive function processes of planning, metacognitive strategies and self-monitoring, by actively involving the child in reflecting, has effects on cognitive functioning, including simple working memory performance.

However, more research is needed on the design of remediation with working memory training, since a finding was that no transfer to arithmetic or reading and writing skills occurred after training in the two training conditions, contrary to the findings of for example Holmes et al. (2009) and Dahlin (2010) proposing working memory training, but in line with the meta-analysis by Melby-Lervåg and Hulme (2012).

The question of far transfer from cognitive training to the school subject domain remains a long-standing challenge. Barnett and Ceci (2002) suggested that the challenge of far transfer (for example from cognitive training to school subjects) can be understood in relation to two overall factors: the *content* (what is transferred) and the *context* (when and where it is transferred from and to). Following this, the content of the exercises in the working memory training program (Cogmed, 2009) used in Study II was mainly free from content in school subjects (texts to comprehend, maths problems to solve, etcetera). In other words, the content of the tasks in the working memory-training program requires far transfer as such. When it comes to the context, the transfer was to be made from the training condition to the classroom by the child, more or less spontaneously, possibly with support from the teacher.

By the metacognitive strategy training we intended to address both content and context factors by enhancing complex executive function in the children. The children in the metacognitive strategy training were engaged in analyses of the content and the context of the working memory training, and the semi-structured design intended to stimulate planning, goal-formulation, strategy use and metacognitive self-monitoring during the working memory training, and explicit transfer to the school domain.

The results from Study II indicate that we got halfway, to near transfer in the visuospatial domain. We can conclude that more needs to be done in order to reach far transfer. From a complex executive function - metacognitive and planning ability – perspective, the question is if more effort should have been put into training conscious awareness of transfer per se. This would imply that more effort should have been used in remediation to foster goal-directed planning for transfer, raising metacognitive awareness of the process of transfer itself. More research in this area is needed, particularly how to foster these processes in the ecologies of the school environment. Research using multiple measures of working memory, executive functions and metacognition would also be needed in order to further explore these processes.

Besides further elaborating on the training regimen and the design of metacognitive strategy training and its use in the complex ecological environment of school, it is possible to develop the design of the computer-based working memory training program in terms of content and context, following the taxonomy proposed by Barnett and Ceci (2002). Working memory training that does not require far transfer, but uses school subject content, as part of the program in the exercises, would be an interesting area of further inquiry. This development would be in line with Cowan's embedded process model, which also allows for more abstract information, goals and rules, like those involved in mathematics learning, to be processed. Stressing even more explicit training of transfer not only from the training to school subjects but also back and forth between training tasks and school subjects would be another possible development. In any case, these suggestions would require more active participation from the adults in the remediation, and thus a more elaborated and well-planned training regimen. In this respect, there seems to be no shortcuts to far transfer.

5.4 The relation between working memory, working memory training and mathematics in school

In Study III the aim was to examine the contribution of different working memory measures to performance on the national curriculum assessment in mathematics in Sweden, in a sample of children with special educational needs in third grade. In particular, we were interested in the predictive role of different types of working memory measures on mathematical attainment in school. It was consequently also a follow-up of the working memory training in Study II, so we wanted to scrutinize possible transfer effects from the working memory training into the domain of mathematics in school.

Surprisingly, baseline levels of visuospatial working memory did not correlate with any of the national curriculum maths tests, while auditory working memory correlated to three out of six subtests, and the maths total score. This was inconsistent with some findings on the role of working memory in mathematical ability among children with special educational needs (Andersson & Lyxell, 2007) even though it was partially in line with some findings proposing that working memory contribution varies for different mathematical domains (Nyroos & Wiklund-Hörnqvist, 2012). The value of the division between auditory and visuospatial working memory could be discussed. Some researchers argue for modality- and domain-specific working memory while others perceive working memory as a domain-general function (Cowan, 2014).

The maximum working memory training performance measure (Max Index WM), drawn directly from the working memory-training program, however, showed significant and high correlations to all maths subtests as well as the total maths score. The hierarchical regressions showed that, controlling for the baseline measures of auditory working memory and initial baseline working memory training performance (Start Index WM), the maximum working memory training performance measure (Max Index WM) added substantial variance on the mathematical total achievement and on four out of six maths subtests. Following these results, a number of interpretations are possible.

Firstly, our analysis suggests that the working memory capacity was enhanced during working memory training, and tentatively, that there was a transfer to mathematics performance in school (at least to performance during the national curriculum assessments) from the working memory training. The results should be interpreted with caution though, since the sample of children was small and there was no control group to compare with. The results are however important, since studies of effects of working memory training on performance on national curriculum assessments in mathematics for children with special educational needs are few. More research is generally needed on effects of cognitive training on ecologically valid measures like national curriculum assessments in school, particularly on samples of referred children with special educational needs.

Secondly, we need to reflect on the nature of the maximum working memory training performance measure. It was gathered at the end of the working memory training period and represents optimal performance after intervention. As such, the construct of optimal working memory performance is different to the pre-intervention measures of working memory, consisting of classical baseline measures, often used in assessment of children with special educational needs. In the hierarchical regressions we also controlled for pre-intervention levels, leaving us not only with an optimal working memory performance measure, but a *change* measure accounting for preintervention levels of working memory. Thus the results could be interpreted in line with research arguing for a stronger predictive validity of dynamic assessment (DA) measures involving change compared to static baseline measures (Caffrey, Fuchs & Fuchs, 2008). This has bearing on assessment practices for children with special educational needs, and serves to advocate the use of more complex measures of cognitive functioning when assessing children with special educational needs.

Thirdly, while the auditory and visuospatial working memory measures are tapping simple working memory span and storage, the composite working memory training performance measures that are gathered during working memory training (Start and Max WM Index) could be considered as more direct measures of complex working memory and/or executive function deployed during the training. This interpretation would be in line with previous research arguing for the higher predictive capacity of complex working memory processing measures in predicting higher-order cognition tasks (Unsworth, Redick, Heitz, Broadway, & Engle, 2009), including mathematics. Also, the maths tasks in the national curriculum assessment, used as outcome variables, generally consist of complex mathematical tasks in different subdomains of maths, and therefore the greater predictive capacity of a complex composite measure like the Max WM index is logical. For assessment professionals but also for teachers, children's performance on complex cognitive tasks could be seen as informative of their predicted performance in mathematics in school, especially in contrast to their performance on simple working memory tasks.

In the intersection between complex working memory processes and executive functions, the results are in line with previous research, that has shown that measures of executive function work as good predictors of math learning disabilities (Toll, Van der Ven, Kroesbergen, & Van Luit, 2011) and more complex executive functions such as planning, self-monitoring and cognitive flexibility predict academic achievement (Best, Miller & Naglieri, 2011). Following these results from Study III, we therefore turned our attention to the role of working memory and complex executive function in Study IV, in order to contrast and clarify their respective role in assessment and learning, in mathematics in particular, for children with special educational needs.

5.5 Working memory, complex executive function and mathematical learning difficulties

The final study (IV) strengthens the hypothesis that complex executive function is a crucial component in understanding learning difficulties in children with special educational needs, especially in the field of mathematics. The children with special educational needs in this sample showed low performance on both working memory (especially simple working memory span and storage) and complex executive function as measured by planning processes. The generally low performance was in line with previous studies showing that low working memory as well as problems with executive functions are common among children with special educational needs (Alloway, Gathercole, Adams, & Willis, 2005; Pickering & Gathercole, 2004).

The second and central finding, that only complex executive function significantly and substantially predicted risk for mathematical learning difficulties, over and above working memory, was also is in line with previous research (Bull & Lee, 2014; Kroesbergen, Van Luit, & Naglieri, 2003; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011).

These results lead to the conclusion that the role of complex executive function, involving planning and metacognition, should be examined in children with special educational needs to a greater degree, particularly when dealing with mathematical learning difficulties. In an assessment context, the results also show that the Planning index of CAS is a valid measure of complex executive function in this regard. More research on the role of complex executive function using measures from different mathematical subdomains could be a possible future direction.

The results also suggest that a definition of working memory that stresses more simple processes (i.e. span and storage) at the expense of more complex processes can lead to an overestimation of the role of working memory in complex learning in school. In assessment context this implies a precaution when using and interpreting the Working Memory index from WISC-IV. The results also tentatively suggest that simple working memory is to be regarded as a non-specific measure, when it comes to differentiating learning difficulties in children with special educational needs.

Geary (2013) stresses that besides complex learning of mathematical systems in different domains (for example number magnitudes), the problem solving system is paramount in the processing of mathematical thinking. In study IV we have shown, in line with Geary's arguments, that mathematical learning including problem solving requires substantial planning and metacognitive processes, particularly for children with special educational needs in this area.

5.6 Implications and concluding remarks

To conclude, the implications for the results from studies II-IV can be summarized in relation to the three issues of the purpose of assessment to inform remediation, teaching and instruction, explored initially in Study I: Firstly, how were working memory and complex executive function in children with special educational needs related to curriculum goals and school subject performances? This also involved discussing the concepts of working memory and complex executive function and their relation to each other. Secondly, regarding tools, approaches and remediation, were assessment of working memory and complex executive function valid tools, and was working memory training including different training conditions a valid remediation for children with special educational needs? Thirdly, regarding a metacognitive strategy training remediation addressing complex executive function, as mediated by the teacher, did it produce effects and help the teacher to adapt the child's learning, by mediating complex executive function processes? In the following sections the implications are summarized:

5.6.1 Implications for assessment

- The working memory profiles of children with special educational needs should be scrutinized to a greater degree if working memory training is to be used, since the referred children with special educational needs did not exhibit clinically low working memory profiles, but showed elevated levels of difficulties in auditory working memory, reading, writing and arithmetic. Low working memory particularly was indicated in children with low arithmetic performance.
- However, when examining the role of simple working memory span measures, they are not good predictors of performance in different subdomains of mathematics in school in children with special educational needs. When adding complex working memory performance measures, and accounting for preintervention levels, predictive capacity improves substantially. This implies the need to consider more complex and dynamic working memory and executive function measures in assessment of children with special educational needs.

- Complex executive function is to a greater degree involved in mathematical achievement and development of risk for mathematical learning difficulties in school for children with special educational needs. Simple working memory can be considered as a more non-specific cognitive function in learning in school. Therefore, complex executive function should be assessed to a greater degree, in assessment and remediation for children with special educational needs, particularly for children at risk for mathematical learning difficulties.
- In a broader context, assessment for children with special educational needs (including assessment of working memory and complex executive function) should contribute to the pinpointing of the needs of the child, and particularly support teachers understanding of how remediation can be designed for children. In this matter, a metacognitive strategy training framework seems to play an important role in supporting an optimistic perspective on cognitive functions and their plasticity, in school.

5.6.2 Implications for remediation and teaching

- Regular working memory training primarily focusing on training of simple working memory by adaptive span-training and to lesser degree complex working memory does not seem to produce near or far transfer effects and should be used with precaution.
- Mediation from the teacher is advised, addressing complex executive function in form of goal-formulation, planning, metacognitive strategy use and self-monitoring. It enhances the effects of working memory training, in direct measurable performance during working memory training. It also produces near transfer effects to visuospatial working memory.
- However, neither working memory training condition produces far transfer effects on reading and writing. Tentatively, working memory training produces far transfer effects on mathematical performance in school six months after completion.
- Tentatively, remediation targeting complex executive function applied in school context can produce effects in simple working memory span performance, in line with previous conceptualizations of executive function (Luria, 1976; Lezak, 1982) as well as working memory models involving processing of more complex information orchestrated by the prefrontal cortex (Cowan, 2012; D'Esposito & Postle, 2015).

We can also add that regularly analysing curriculum and syllabus objectives, as well as classroom practice in teaching, in order to understand the role of different underlying cognitive functions, among them complex executive function, is important in order to adapt and support learning for children in general, and children with special educational needs in particular. The role of the teacher as a mediator in this process is central. The active participation of the child in reflection on his or her own learning is another central aspect, and a metacognitive strategy training framework offers opportunities in this regard. A compensatory perspective on children with special educational needs might of course be important in order to not overburden the child temporarily in learning, but this can strengthen a deficiency-oriented perspective on the child resulting in lowered expectations on the abilities of the child. This thesis has argued for a needs-oriented optimistic perspective on children with special educational needs and also the plasticity of working memory and executive functions, beyond a compensatory perspective. From the results of the four studies it can be concluded that an optimistic perspective on children's learning and development is important, in order to counteract a static deficiency-oriented approach, especially regarding children with special educational needs, in assessment and remediation.

To conclude, school places a great deal of expectations on children from first to last grade. With Luria's seminal words in mind, from the introduction of this thesis, are we organizing learning appropriately and are we providing sufficient tools for learning? The conclusions in this thesis, at least in part, points to the importance of helping children to develop and master their higher mental functions - complex executive function of planning, goal-setting, self-monitoring and metacognition - in the course of learning, in the complex environment of school. This thesis has hopefully shown that stressing the complex executive function of planning and metacognitive processes has potential to contribute to both clinical and school psychological as well as special educational and teaching practices. It draws attention to the need of more systematically assessing and designing remediation with planning, metacognition and self-monitoring in mind. It also serves to remind that in contrast to the simple measures of different cognitive functions that we use in assessment and research, or the relatively controlled situation in computer-based training settings, when instead exploring these processes and settings in the ecological environment in the everyday life of school - where a myriad of interactions, relations and intertwined processes take place - new and more complex relations between cognition and learning emerge.

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8. APPENDIX: STUDIES I-IV