Cognitive Interventions for Mathematics Learning Disabilities

Dianne L. Ballance

ID#00939966

University of Calgary

APSY 658
Cognitive Interventions for Mathematics Learning Disabilities

Children with learning disabilities can be found in almost every classroom. It is estimated that between 5 and 8% of children have difficulties in mathematics (Fuchs et al., 2005; Geary, 2004; Kroesbergen & Van Luit, 2003; Wendling & Mather, 2009). Difficulties in mathematics may result from numerous sources including neurological impairments, intellectual functioning, motivation, and strategy acquisition and application (Kroesbergen & Van Luit, 2003; Wendling & Mather, 2009). Children with serious difficulties that persist over time are often diagnosed as having a mathematical learning disability (MLD). To correspond with the research, MLD in this paper refers to children with low achievement scores in mathematics relative to their IQ. Due to the hierarchical and cumulative nature of mathematics it is critical to provide close monitoring to meet the needs of individual children with MLD (Andersson, 2009; Wendling & Mather, 2009). The focus of this paper is cognitive interventions for children with MLD. Cognitive characteristics and neurological underpinnings, and general cognitive strategies in current research will be presented to provide the framework for a closer examination of self-regulation (SR), and the strategic content learning (SCL) model of instruction through Upah and Tilly’s (2002) best practices model of interventions.

Cognitive Characteristics and Neurological Underpinnings

An understanding of the cognitive and neuropsychological factors that contribute to MLD is important for the assessment and identification of math disabilities, as well as for the selection and validation of effective interventions (Wendling & Mather 2009). Children with difficulties in math are very heterogeneous, however some general characteristics can be described (Kroesbergen & Van Luit, 2003). In general, students with MLD typically display deficits in mathematics calculation and/or reasoning skills (Lyon, Fletcher, Fuchs, & Chhabra, 2006).
Specifically, they have an immature understanding of certain counting principles and underdeveloped number sense, use immature problem solving strategies, commit frequent procedural errors, and have difficulties with approximation, time telling, errors in judgement and reasoning, and retrieving basic facts from long-term memory (Andersson, 2008; Garrett, Mazzocco, & Baker, 2006; Geary, 2004; Passolunghi, 2011).

The delays and deficits appear to be related to a combination of disrupted functions in cognitive and neurological mechanisms (Geary, 2004). Researchers have identified several neuropsychological correlates that can affect math performance including: working memory, executive functions, attention, and processing speed (Andersson, 2009; Bull & Scerif, 2001; Geary, 2004; Maccini, Mulcahy, & Wilson, 2007; Montague, 2007; Passolunghi, 2011; Wendling & Mather, 2006; Xin, Jitendra, & Deatline-Buchman, 2005). Some research suggests that phonological and visuospatial abilities affect math ability; however support for this is inconsistent. Although research shows evidence for cognitive and neuropsychological correlates they still have not been fully determined, and underlying sources for delays and deficits are complicated and nuanced (Geary, 2010). There are multiple brain systems engaged in mathematical learning, and a developmental delay or deficit in any one of the areas could result in functional deficits (Ansari, 2010). Therefore, MLD is not due to a single underlying deficit. It should also be noted that Ansari (2010) suggests that the role of development in neurocognition is an important factor to consider when reviewing the research and making conclusions about cognitive processes of children with MLD. The importance of adopting a developmental approach impacts the practice of ongoing assessment and adapting interventions.

Specifically, memory deficits may lead to difficulties in the acquisition of and remembering of math knowledge (Kroesbergen & Van Luit, 2003). This results in inadequate
use of strategies for solving math tasks and application of cognitive and metacognitive strategies (Kroesbergen & Van Luit, 2003). Deficits in generalization and transfer of learned knowledge to new and unknown tasks are also associated with problems in memory (Kroesbergen & Van Luit, 2003). Working memory (WM) is implicated in basic fact fluency and problem-solving (Desoete, Roeyers, & De Clercq, 2003; Fuchs et al., 2005). Attention and speed of processing may underlie the general pattern of WM difficulties and problem-solving skills (Fuchs et al., 2005; Passolunghi, 2011; Swanson & Beebe-Frankenberger, 2004). WM plays a critical role in integrating information during problem solving, and activating relevant knowledge from long-term memory (Swanson & Beebe-Frankenberger, 2004). It is clear that memory is an integral component in mathematical ability.

The central executive controls the attentional and inhibitory processes needed to use procedures during problem solving (Geary, 2004). Difficulties are seen in monitoring and sequencing the steps of problem-solving, and in switching and evaluating new strategies (Bull & Scerif, 2001; Geary, 2004). The ability to inhibit irrelevant information is also implicated in differences in working memory capacity and ability to problem-solve (Bull & Scerif, 2001; Passolunghi, 2011; Swanson & Beebe-Frankenberger, 2004). It has been found that children with MLD have higher rates of intrusion errors (Passolunghi, 2011). Main difficulties for children with MLD include slower performance due to reduced attention focus, inhibiting information, and switching between strategies (Bull & Scerif, 2001). Inhibitory processes are relevant to both problem-solving and calculation ability (Passolunghi, 2011).

**Cognitive Intervention Strategies**

Given the deficits in working memory, executive functions, and speed of processing and the resulting difficulties in math performance, intervention targeting cognitive skills will likely
benefit children with MLD. Cognitive strategy instruction focuses on teaching a range of
cognitive and metacognitive processes, strategies, or mental activities to facilitate learning and
improve performance through use of direct and explicit instruction (Montague & Dietz, 2009).
Children with MLD have showed lower metacognitive abilities in their judgement, prediction,
and evaluation skills that contribute to recognizing their errors, problem-solving abilities, and are
often overconfident of their abilities (Garrett et al., 2006). Cognitive strategy intervention is
particularly well suited for children with MLD as it provides the necessary cognitive tools
needed to facilitate understanding and task completion, and explicit instruction in metacognitive
skills and cognitive strategies has been found to be successful (Desoete et al., 2003; Maccini et
al., 2007; Owen & Fuchs, 2002; Xin et al., 2005; Montague, 2009). Due to the heterogeneity of
MLD, matching the cognitive intervention to specific cognitive abilities at the appropriate
developmental level is important (Owen & Fuchs, 2002).

Best Practice Interventions

Upah and Tilly (2002) present a twelve step model as the best standard evaluating quality
interventions. The quality indicators include: behavioural definition, baseline data, problem
validation, problem analysis, goal setting, intervention plan development, measurement strategy,
decision making plan, progress monitoring, formative evaluation, treatment integrity, and
summative evaluation. These indicators are addressed within the four stage problem-solving
processes that include: problem identification and analysis, plan implementation, and program
evaluation. The model provides the framework for the following evaluation of SR and SCL.

Self-Regulation Strategies

Self-regulation is a prominent cognitive strategy that incorporates stages of self-
assessment, self-recording, and self- instruction (Montague, 2007; Owen & Fuchs, 2002). An
essential component of self-regulation is a child’s metacognitive awareness of their own processes of learning or engagement in a task (Labuhn, Zimmerman, & Hasselhorn, 2010). Self-regulation is integral to cognitive strategy instruction as it directs and guides children in the application of mathematical processes, and is essential to effective and efficient math problem-solving (Montague, 2008). Montague (2007; 2008) completed reviews of the research of self-regulation instruction for math difficulties and concluded that it was effective for elementary, middle, and high school students. Self-regulation applied to mathematics performance can be described as how a child interprets the task demands (by representing a problem to determine what it is asking, recognizing the need to learn a mathematical concept that can be applied to solve problems) and then based on a clear understanding of task objectives they select, adapt, or invent strategies for learning or problem solving, self-assess outcomes, and redirect learning if needed (Butler, Beckingham, & Novak Lauscher, 2005). Two studies of self-regulated strategy intervention were selected for evaluation (Fuchs et al., 2003, Labuhn et al., 2010). The purpose of the studies was to evaluate SR effects on mathematical problem solving.

**Problem Identification.** In terms of providing an objective, clear, and complete behavioural definition the studies did not fully meet Upah & Tilly’s (2002) criteria as the nature of the research design was exploratory in nature and the behaviour problem (math problem solving difficulties) was referred to on a general level only. The studies included samples of children of varying abilities and intervention was not defined or individualized. The target behaviour was use of self-regulation strategies during math performance based on current classroom curriculum. Defining the behaviour more specifically would be important for generalization of results and when designing individualized assessments.
Baseline data demonstrating poor self-regulation was also insufficient in the studies. Fuchs et al., (2003) collected teacher ‘designation’ of student math achievement as high, average, or low; which is not a measure of self-regulation strategies. This study is able to look at aspects of math functioning in this baseline data, but it does not confirm the existence of a specific lack of self-regulation strategy use in their sample. Fuchs et al. (2003) may be relying on the theory and research that links problems in self-regulation and math difficulties where specific measures of self-regulation abilities are measured directly; however, this means that their study is lacking in meeting this indicator of a quality intervention. However, Labuhn et al. (2010) did collect pre-test information for baseline data for math problem solving and for self-evaluation (a component of SR).

Baseline data was also limited to a one time measure which doesn’t allow for providing the documentation of problem validation. It is not possible to determine if self-regulation strategy use is specifically related to existing problems (and to what extent) in math performance prior to intervention treatment. Without problem validation it is not possible to determine if SR strategy intervention is the appropriate choice. Again, the studies may be relying on previous theory and research demonstrating the benefits and use of SR for students with difficulties in math. Overall these studies did not meet all of the criteria for best practice standards in problem identification.

**Problem Analysis.** Problem analysis in the studies is restricted to prior research and theory. The studies identify relevant known information and make relevant hypothesis based on existing research, but do not complete this in relation to their specific studies. It is only assumed that poor performance in math is related to ineffective and immature self-regulation and strategy use. They also do not complete any further assessment beyond baseline data prior to
intervention. It is therefore impossible to link assessment to the intervention design. Relevant sample data is collected that preserves the quality of the research, but this doesn’t support the effectiveness of the intervention. There is no way for the studies to confirm the validity of their hypotheses without this problem analysis information.

**Plan Implementation.** Plan implementation appears to be an area of strength in the studies. Careful consideration was evident in the development and implementation of the self-regulated strategy intervention. Both studies clearly intended to improve mathematical problem solving using a self-regulation intervention approach. The Fuchs et al. (2003) study also allowed for students to set goals for their performance, monitor and graph their performance, and identify opportunities where they could transfer their skills. This study also was very clear on the development and implementation of the intervention. Four math problem-types from the curriculum were chosen to incorporate the SR strategy, and teaching sessions were carefully planned and all the procedures outlined (scripts, length, duration, development of strategies). Four measures of self-regulation processes were completed (transfer measures and a student SR questionnaire). All data collection and data analyses procedures were clearly defined to meet research standards, which also meet quality intervention standards. The Labuhn et al. (2010) study did not allow students to create goals for themselves specifically, but did utilize a feedback component that highlighted and monitored their performance. Implementation was again very specific, incorporated curriculum and SR strategies, and defined all the processes, scripts, and phases of the intervention. This study had extensive measures (seven total) to collect data of which some were related to SR. Again, conclusions were based on data analysis. Overall, the studies met the standards of best practice in plan implementation.
Program Evaluation. Program evaluation is inherent in research study design to address if the intervention is working, how the intervention was implemented, and if the intervention was successful. Progress monitoring in the studies involved data collection in each study as measures to monitor the progress of the children’s math performance and SR strategy use. However, these measures were not directly related to the baseline data measures used in problem identification. The resulting problem is that the change in measurement procedures makes it difficult to conclude that they are caused by changes in performance, and may call into question the effects of the intervention (Upah & Tilly, 2002).

Formative evaluation ideally occurs throughout the intervention to determine if the intervention is working (Upah & Tilly, 2002). Changes to intervention to meet the needs of the child are made possible with this evaluation. Research design does not support making changes to the intervention during the treatment phase. Both studies did however include data collection throughout the intervention; Fuchs et al. (2003) utilized goal setting and graphing to monitor performance, and Labuhn et al. (2010) utilized feedback and graphing to monitor performance. The primary concern with the Labuhn et al. (2010) study is that the intervention was a one-time session which cannot be evaluated over time. The studies are able to use these evaluations in comparing performance to goals and in developing their conclusions, but did not attempt to use them for individualizing interventions which would be needed to meet quality standards in real life settings.

Treatment integrity is a primary concern that was addressed in both studies. Careful consideration was given to ensure that the intervention was implemented as planned. In the Fuchs et al. (2003) study the intervention was carefully integrated into math curriculum, and research assistants were responsible for teaching the first problem-solution lesson. Teachers
taught the remaining of the sessions, but research assistants were present for each session. In addition, sessions were scripted and studied to ensure consistency of information. Audio-tapes, classes, and lessons were sampled equitably and the percentage of ‘key information’ was measured. The Labuhn et al. (2010) study also incorporated the SR strategies into the math curriculum with specific steps for implementation. Research assistants were responsible for conducting the intervention, although there were no specific procedures for measuring treatment fidelity which may compromise this study.

The purpose of the studies was to evaluate the effects of SR on math performance, and used a comparison of pre and post test data for summative evaluation to base the conclusion that the interventions were successful. A potential problem with their conclusions may be related to some differences in the different measures used to obtain this information. Overall, the studies have diverse rates of acceptability regarding the standards of best practice in program evaluation.

**Strategic-Content Learning**

Strategic content learning is an instructional model that utilizes self-regulation strategies to improve mathematics learning. SCL fosters students’ engagement in the cycle of self-regulated activities and supports the construction of knowledge, conceptions, and beliefs for effective self-regulation (Butler et al., 2005). Consistent with research, SCL involves students to actively reflect on their learning to formulate and search for connections between problems and understanding mathematical structures (Butler et al., 2005). SCL also follows the guidelines in the literature for dynamic, curriculum-based, contextualized forms of assessment to guide interventions in mathematics (Butler et al., 2005). The model is responsive to individual’s needs and can be applied within a practical context (such as learning assistance programs) (Butler et al., 2005). SCL has four instructional principles: self-regulation support is integrated into
instruction, students are active interpreters of information, learning in mathematics involves guided (re)construction, and learning pursues a clearly defined goal (Butler et al., 2005). This is accomplished through ‘strategic questioning’ and construction of cognitive and metacognitive strategies. Teachers guide students to develop, adapt, or invent personalized strategies. In practice SCL looks like a teacher guiding students to self-regulate completion of classroom work through jointly interpreting the task, establishing a context for strategy development, and collaboratively solving the problem through use of cognitive strategies, and cues to reflect on learnings (Butler et al., 2005). The case study SCL research completed by Butler, Beckingham, and Novak Lauscher (2005) was chosen for evaluation.

**Problem Identification.** In terms of defining the behaviour, participants for the study were chosen based on formal diagnosis of MLD (for one student), involvement in learning assistance programs, and chronic underachievement in mathematics. Their unique difficulties were defined through collection of baseline data which was then used to tailor the intervention progress on an individual basis. For example, one student’s problem behaviour was defined as difficulties in self-regulated learning, lack of strategies, and difficulties constructing conceptual and procedural knowledge. Another student’s problem behaviour was defined as math computation and problem-solving difficulties. The problem behaviour for the last student was defined as problems in self-regulation of learning (interpreting tasks, working deliberately, rechecking her work) in task organization and management skills. It is clear that the behaviour definitions were clearly related to target behaviours, and were linked to the intervention; therefore it meets the standards of best practice.

Baseline data was collected in the study through multiple strategies. Background information was collected through review of Individual Education Plans (IEPs) and
COGNITIVE INTERVENTIONS FOR MLD

psychoeducational assessments. A meta-cognitive questionnaire was used to assess conceptions about mathematics learning, knowledge of personal strengths and weaknesses in math, knowledge about strategies for learning math, and approaches to self-assessment. Pre-test performance was collected through two tests. It is clear that the study established student’s current level of functioning and difficulties from repeated measures in the primary settings it occurs, and is related to self-regulation processes and math performance. Therefore the study again meets the criteria for best practice.

Problem validation was also evident in the types of assessments that were completed prior to the intervention (IEP’s, psychoeducational assessments, chronic underachievement) and from the baseline data that demonstrated discrepancies between the participants’ level of performance compared to their peers using both local and standardized measures. Intervention was warranted in each case. To conclude, the study met acceptable levels of problem identification to meet best practice standards.

Problem Analysis. The information gained from the problem identification stages was useful in creating hypothesis regarding why difficulties were occurring for the participants. All known information was gathered and analyzed, and unknown information was collected through the observations and tests. The assessment information was linked to the intervention program and even individualized to account for differences between students. The study meets best practice standards in this area.

Plan Implementation. Goal setting was achieved through direct correlation to the defined behaviour problems that were unique for each student. Goals were linked to teaching individualized SR interventions that focused on the outcomes for each child for the duration of the intervention. In addition, daily goals were created through the intervention program for each
session, and focused on the need of a particular math assignment or question. Strategies were continually elaborated upon that ultimately building a combination of problem-specific and metacognitive steps (Butler et al., 2005).

The intervention program was based on SCL and SR theory and research, but was tailored for each student depending upon their individual profile. This involved use of some specific strategies (‘strategic questioning’, working backwards, self-checking, etc.) but was flexible to meet the current task demands. A bank of personalized strategies was created for students to use to help in further development of cognitive strategies and for transfer of skills; which was included in the research design. Careful thought went into implementing the SCL method while utilizing a variety of SR strategies on a ‘as need’ basis. The weakness with this approach is that not all the procedures would be clearly outlined for each session, and it would not pass the ‘stranger test’. Only a qualified person with sufficient background knowledge and experience would be able to implement SCL.

Measurement strategies were extensive and included the same type of measures used for collecting the baseline data. Obtaining accurate information was a primary goal of the study in order to complete the cross-comparison assessment at the end of the intervention. Specific measurement strategies are further discussed under program evaluation.

At the outset of the study all data collection procedures were determined to aid in data-based decision making throughout the intervention. Upon reading the case study descriptions it was evident that progress monitoring techniques contributed to making decisions about ongoing intervention needs. Overall, the study met acceptable levels of program monitoring to meet best practice standards.
**Program Evaluation.** Progress monitoring was conducted throughout the intervention. Data was collected through researcher observations, field notes, teacher’s daily descriptions of instructional interactions and student progress (on teacher reflection forms), videotapes of instructional sessions, student work samples, performance on classroom tests, and copies of personalized strategies developed by students. Four tests were completed during the intervention program, and two post tests were completed after the intervention. Integrity was ensured by the data collection process (data was labelled and organized into case study binders) and data was converted into soft data files for cross-case observations could be constructed. The multiple sources of evidence were used to provide the complete picture of how SCL was linked to development of self-regulation.

Formative evaluation was completed through comparing progress monitoring in relation to each student’s goals. Changes in mean, level, and trend were examined for each student and data tables were provided. In addition, in-depth analyses of student-teacher interactions showed positive outcomes and SR development. A weakness in the study is that maintenance and generalization were not a primary focus and could have been addressed in more detail.

Treatment integrity involved the researchers carefully scrutinizing all the materials and the processes of intervention. The research team supported teachers through visits, co-teaching, observation, and debriefing. During data analysis the research questions were kept in mind, and patterns were defined in a systematic and unbiased way to ensure that conclusions could reliably be linked to the catalogued evidence.

Summative evaluation for each student was completed by comparing the difference between pre, mid, and post test data. The final step in the analysis was to complete a cross-case comparison through independently reviewing the cases and strategy use to compare and then
construct final themes. However, there was no indication that progress would be monitored after the conclusion of the intervention. In general, the study met acceptable levels in program evaluation to meet best practice standards.

**Conclusion**

Math learning disabilities are a real concern for many students in school settings today. The extant research links several cognitive and neuropsychological correlates to difficulties in math performance. Working memory and executive functions appear to be the primary areas, but the field is still developing explanations of the complex relationships of these deficits and the relationships to math functioning particularly from a developmental perspective. The literature suggests that cognitive strategies are evidence-based interventions for improving math performance, particularly for children with MLD. Self-regulation is a common intervention, and a detailed evaluation of its use in research and through an instructional method (SCL) was conducted. Specifically the research on SR had weaknesses in problem identification and problem analysis, mixed results in program evaluation, and strengths in plan implementation. The comparison does raise some concerns regarding the conclusions about the efficacy of interventions, but perhaps best standards in research and best standards in practice cannot be compared at the same level. The Upah & Tilly (2002) article appears to be fit evaluation of school-based interventions better than exploratory intervention research. The research on SCL as an instructional method utilizing SR was much more promising, perhaps due to the case study design conducted in a real school setting, and met acceptable criteria for Upah & Tilly’s (2002) best standards of practice. All children that have math difficulties require special attention that focuses on quality interventions. It is up to the practitioner to evaluate these interventions in practice to ensure that they meet the standards for quality interventions.
References


