Increasing Children's Working Memory Capacity In Schools: Preliminary Evaluation Of A Collaborative Card-Based Programme

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Abstract

Working memory, particularly verbal working memory, has long been recognised as foundational to children's ability to learn. Research has demonstrated that practice on computerised training programmes can increase children's working memory capacity. However, there are inherent difficulties which may restrict these programmes application within the school context. The current research presents findings from a preliminary evaluation study into the effectiveness of a novel whole-class programme to increase children's working memory capacity. The programme involved pairs of children engaging in a series of five different card-based working memory activities in a mainstream primary school classroom for fifteen minutes a day, over a six-week training period. Measures of children's working memory demonstrated significant gains in working memory and verbal short-term memory. These improvements were significant at both post intervention and at two month follow up. The demonstration of a practical and effective whole class working memory training programme holds considerable potential to increase children's capacity to learn and achieve.

Keywords: working memory, verbal working memory, whole-class intervention, card-based intervention, collaborative learning

Introduction

The most influential and scientifically defensible model of working memory (WM) has been advanced byBaddeley (2001, 2010). This multi-component model of WM demonstrates a flexible system, comprising of four interconnected but functionally distinct subcomponents. The model proposes that the Phonological Loop and Visuospatial Sketchpad are responsible for the storage of auditory and visual information respectively, while the Episodic Buffer stores information from different modalities to allow for a multi-dimensional coding that binds information into an integrated episodic memory. Fundamental to WM is the Central Executive which controls higher-level attentional and executive processes that process and transform the information stored within these subsidiary systems.

The proficiency of WM develops considerably from preschool through adolescence. There is a linear increase in WM performance between 4 and 12 years, levelling off towards 15 years (Gathercole, Pickering, Ambridge, & Wearing, 2004). This maturation in proficiency corresponds to changes in fronto-parietal grey matter structures and their white matter inter-connections (Thomason et al., 2009). However, there is a substantial degree of individual variability in WM abilities. For example, a typical class of nine year old children is likely to include individuals whose WM capacities vary from that of the average performance of 7–12 year olds (Gathercole et al., 2004).

WM is implicated in providing the foundational abilities on which children achieve many important educational skills. In particular, there is substantial evidence of a causal relationship between children’s WM abilities and their attainment in school. For example, children's WM capacity is fundamental to their achievement in key academic domains such as reading (Swanson, Xinhua, & Jerman, 2009), spelling (Ormrod & Cochran, 1988), reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009), and mathematics (Swanson & Kim, 2007). Assessment of WM between the ages of 29-41 months is also an excellent prospective indicator of classroom engagement, number knowledge and receptive vocabulary at 74 months of age (Fitzpatrick & Pagani, 2011). Furthermore, in a longitudinal study, Alloway and Alloway (2010) demonstrated that five year olds’ WM is a better predictor of academic success at age eleven than measures of general intelligence.

It is estimated that approximately 10-15% of school aged children experience some form of WM difficulty. However, these difficulties are often misinterpreted as more generalised attention or intelligence difficulties (Gathercole, Lamont, & Alloway, 2006). As WM is such a foundational ability, children with poor WM do not often catch up with their peers (Alloway, Gathercole, Kirkwood, & Elliott, 2009).

Working Memory training programmes

Until recently, it seemed unlikely that the adverse consequences of low WM ability could be overcome. Unlike many other cognitive abilities, WM appeared to be relatively impervious to influences in general environmental experience and educational opportunity (Engel, Santos, & Gathercole, 2008). However, recent research suggests that computerised WM training can significantly improve WM for children with poor WM (Holmes, Gathercole, & Dunning, 2009), children with ADHD (Beck, Hanson, Puffenberger, Benninger, & Benninger, 2010) and typically developing preschool children (4-5 year olds) (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009) and adolescents (Løhaugen et al., 2011).

However, while computerised training methods hold promise, there are theoretical limitations to their potential. Among others, tasks that purport to invoke verbal WM may actually bear more relation to developing visuo-spatial WM, because responses on computerised tasks are inherently visual in nature (i.e. clicking a response on the computer screen). Indeed it is often found that computerised training leads to greater gains in visuo-spatial WM over verbal WM (Holmes et al., 2009; Holmes et al., 2010; Klingberg et al., 2005; Thorell et al., 2009). While these authors often note the importance of verbal WM to children's achievement the emphasis of these programmes to increase visuo-spatial WM over verbal WM is rarely discussed.

Furthermore, there are practical difficulties imposed through the use of computer based programs which may restrict their applicability and uptake within the general classroom context (Hermans, Tondeur, van Braak, & Valcke, 2008). Accordingly, due to a relative inaccessibility of these programmes, they are often only feasible to use with individual children who experience the most pronounced difficulties.

The present research aims to evaluate a practical, whole-class WM training programme which engages children through a socially mediated programme of targeted activities which invoke and stretch their individual verbal WM capacity. To the researchers' knowledge, this is the first and only practical programme that has been designed to specifically improve children's WM on a whole-class level.

Developing a whole class WM training programme (MeeMo)

In order to develop a theoretically effective WM training programme which was ecologically valid and usable in the classroom context, a programme development phase was undertaken within a UK elementary school. This included successive focus groups with experienced school-based professionals to ensure the programme was tailored to the contextual realities of the school context. Following this, observations and discussions were held with small groups of children using the prototype materials. This enabled adaptations to ensure that MeeMo achieved an appealing format, and to establish a highly usable programme which children could employ with a good degree of autonomy.

Recognising that attentional modulation is a fundamental component of WM (Baddeley, 2010), and children's level of interest in an activity is central to their subsequent allocation of attention, a key feature of MeeMo was to ensure that it achieved an engaging and immersive experience for children. To achieve this, the design of MeeMo's materials and procedures drew upon frameworks of what creates motivating and appealing games and learning processes (see Chatfield, 2010; Linnenbrink-Garcia, Rogat, Koskey, 2011).

A summary of the key features of MeeMo can be found in Figure 1 below:

- Figure 1 here –

The five WM activities contained within MeeMo were initially developed on principles of Baddeley's WM model (Baddeley, 2001, 2010). A particular advantage of incorporating multiple activities is that the diversity of training experiences each target the central executive component in differential ways, minimise automisation (Morrison & Chein, 2011), and anticipate greater levels of generalisation outside of the training context (Schmidt & Bjork, 1992).

The present research sought to evaluate the outcomes of MeeMo on children's WM. Accordingly, this can be operationalised as follows: Does a preliminary evaluation of MeeMo in a whole-class context for six weeks demonstrate that it is effective to increase children's WM; both immediately after its implementation and at follow-up?

Method

Participants

To evaluate the impact that using MeeMo has on children's WM abilities, a class from an elementary school in the UK was sampled. A year four class (age 8-9 years) was chosen, providing an age range for which WM improvements would lead to considerable long-term benefits, while being age appropriate for the training procedures. The average age of the children was 8 years 7 months (SD=0.27), with an even division of 12 boys and 12 girls. The socioeconomic background of the pupils was mixed, and the performance of pupils at the schools in reading, writing and mathematics was similar to the national average. There was a 97% attendance rate during the programme implementation, with no discernible pattern of absences.

Procedure

To achieve a high level of external validity, there was minimal researcher involvement in the set-up and running of MeeMo, with the main guidance for the teacher being provided through a brief written guide. Children engaged with the MeeMo materials for five days a week, for a total of six weeks. Including using each activity twice during the first week, this totalled 210 minutes (3 ½ hours) of active practice (being the Thinker), distributed across 30 sessions. Fidelity was specifically assessed through a teacher diary, and three observations by the first author; with no discernible alterations being identified to the intended protocol.

Design

To establish whether MeeMo has the potential to improve children's WM, the current design entailed assessing children's WM pre-training (T1), post-training (T2), and at a follow-up eight weeks after the programme has finished (T3). Figure 2 illustrates these assessment points and the related time period intervals.

- - Figure 2 here - -

This design has demonstrated utility in controlling for many extraneous factors, and holds particular advantages for the present study. While it is recognised that a control group would have been preferable to prudently control for maturational effects, these are would to be minimal within the current design due to children's WM typically remaining stable over the course of the 3½ month assessment period (Alloway, 2007; Alloway, Gathercole, Kirkwood, & Elliott, 2008), and there being a relative immunity of WM to influences of general environmental experience and educational opportunity (Engel et al., 2008). In addition, there would be little impact of measurement reactivity from exposure to a pre-test creating carryover effects (Alloway, 2007). Accordingly, the present design holds the potential to indicate whether changes in children's WM can be attributed to training through the MeeMo programme.

Measures

At each of the three time points (see Figure 1) children's STM and WM abilities were assessed using the Automated Working Memory Assessment (AWMA)(Alloway, 2007). As well as having good test-retest reliability and convergent, discriminate and predictive validity, the AWMA has also proven a useful outcome measurement within the context of previous WM training evaluation studies (Holmes et al., 2009; Holmes et al., 2010). Using the AWMA, children were individually assessed, and completed one assessment from each domain of verbal STM (Digit Recall), verbal WM (Listening Recall), visuo-spatial STM (Dot Matrix), and visuo-spatial WM (Spatial Recall).

Findings

Preliminary analysis demonstrated that the sample was representative of the population, with pre-training (T1) performance on the assessments being comparable to the AWMA standardisation sample ($\bar{x}$ = 102.56, SD = 11.35, all p > .05). Furthermore, while there were few anticipated maturation effects over the length of this study (Alloway, 2007; Alloway et al., 2008), standardised scores were employed to minimise any such potential. There were also no significant differences between *processing* scores on the WM tasks (i.e. scores on a judgement task) between time points (all p > .05), indicating that there were no substantial practice effects associated with these tasks.

Estimates of training effects were achieved through a repeated measures MANOVA with one independent variable of time (T1 [pre-training], T2 [post-training], T3 [follow-up]), and four dependent assessment variables (verbal STM, verbal WM, visuo-spatial STM, visuo-spatial WM). Table 1 shows the means ($\bar{x}$) and standard deviations (SD) for all assessments, along with the mean difference ($\bar{x}_{diff}$) scores between assessment periods (T1, T2, T3) and associated effect sizes (η_p^2) where appropriate. Figure 1 further exemplifies these findings through graphically representing the means and confidence intervals from each assessment across assessment periods.

- - Table 1 here - -

There was a significant overall effect of time on children's performance across WM assessments (λ = .17, F[4,16] = 10.00, p < .001. , η_p^2 = 0.83). Comparing pre-training (T1) with post-training (T2), it is apparent that there was a significant gross effect of the training, leading to gains in children's verbal STM (F[1,23] = 43.17, MSE = 53.30, p < .01, η_p^2 = .65), verbal WM (F[1,23] = 12.78, MSE = 195.74, p < .01, η_p^2 = .36), and visuo-spatial WM (F[1,23] = 8.02, MSE = 103.24, p < .05, η_p^2 = .26), while there were no significant gains in visuo-spatial STM (F[1,23] = 4.12, p > .05). Each of these gains across verbal STM, verbal WM and visuo-spatial WM remained significant after the two month post-training follow-up (T3) (all p < 0.5).

Furthermore, a comparison of post-training scores (T2) with follow-up scores (T3) demonstrated that there were no significant decreases in verbal WM (F[1,23] = 2.46, p > .05), or visuo-spatial WM (F[1,23] = 0.14, p > .05), with a significant increase in children's verbal STM (F[1,23] = 4.80, MSE = 48.81, p < .05, η_p^2 = .17)

A significant interaction between the effects of the training and different aspects of WM (*F*[6, 138] = 3.94, MSE = 39.16, $p < .01$, $\eta_p^2 = .146$) indicated that there were significantly more gains in children's verbal STM than their visuo-spatial STM between pre-training (T1) and post-training (T2)(*F*[1,23] = 5.50, MSE = 120.37, $p < .05$, $\eta_p^2 = .19$).

Discussion

Overall, the present findings are promising and replicate previous research in demonstrating that intensive and adaptive WM training can lead to significant and sizeable increases in STM and WM (see Klingberg, 2010; Morrison & Chein, 2011; Shipstead, Redick, & Engle, 2012 for reviews). However, unique to the current research is the first demonstration that a non-computerised WM training programme can improve children's WM. Encouragingly children's verbal STM and verbal WM increased by approximately ten standard score points (a large effect size) over the course of the training programme, with increases remaining significant at follow up.

Additionally a significant increase in verbal STM after the training programme had finished (T2-T3) is observed. This is the first demonstration that STM can continue to significantly increase post-training, and potentially indicates a variety of possible programme design features which have enabled for this to happen.

While the present findings highlight the potential of MeeMo as an effective whole class WM training programme, there are several important areas for future research. These include, incorporating a larger sample size with differential characteristics (i.e. age, baseline abilities, specific conditions) to demonstrate the generalisation of MeeMo's effectiveness; employing an experimental design to comprehensively control for factors such as maturation, history, measurement reactivity and expectancy effects; and tracking WM increases at frequent time intervals to identify the rate of progress and highlight potential ceiling effects. There is an array of unique attentional and motivational features of MeeMo which may have contributed to its effectiveness in improving children's working memory; features which will be important to consider in future WM training programmes. These will now be addressed in more detail.

There is a clear overlap between the notions of WM and attention (Shah & Miyake, 1999). Accordingly, the importance and modulation of attention is frequently considered in evaluation studies of WM training programs. Furthermore, there are emerging indications that those with greater levels of attentional focus during training make the most improvements in their WM capacity (Perrig, Hollenstein, & Oelhafen, 2009). Specifically, attention is generally viewed as a limited-capacity system which is composed of a number of different mechanisms including attentional switching, selective, and sustained attention (McDowd, 2007). These mechanisms overlap with the proposed functions of the central executive (Fournier, Larigauderie, & Gaonac'h, 2008), and are discussed in the context of WM training programmes below.

Attentional switching describes the situation where the focus of attention is alternated between two or more different tasks, cognitive operations, or retrieval strategies (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Accordingly, attentional switching is an important component of any WM training programme (Perrig et al., 2009). However, an examination of the verbal and visuo-spatial activities contained within computerised WM training programmes indicates that they are often related to simple span activities where lists of items are presented. Accordingly, it is only when the list length increases and overwhelms STM capacity that WM resources are likely to be employed. Therefore, these computerised programmes may primarily target STM rather than WM. In comparison, all of the MeeMo activities necessitate both the serial recall of list items and require task specific processing, or transformation of the presented information to achieve the correct response, thereby taxing attentional switching to a higher capacity.

Selective attention, the ability to selectively attend to target information and mental representations while simultaneously inhibiting other automatic goal-irrelevant response patterns, is a key function of successful WM processing (Gazzaley & Nobre, 2012; Miyake et al., 2001). Considering this, it is interesting to note that computerised WM activities present children with opportunities to focus on target information, but have no elements which require the active suppression of irrelevant details. In contrast, an originally unanticipated feature of MeeMo's whole class design is that a high level of irrelevant speech occurs in the classroom during the time of the training, thereby necessitating children to both selectively attend to their partner, while also continually blocking out irrelevant noise. This frequent opportunity to simultaneously train selective attention may have been of considerable benefit to children, and could have contributed to the observed increases in their performance on WM assessments.

Sustained attention has been described as the ability to continuously attend to information over a prolonged period of time (Leclercq, 2002). With two notable exceptions (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; Van der Molen, Van Luit, Van der Molen, Klugkist, & Jongmans, 2010) computerised training sessions last for a minimum of 29.5 minutes per session (cf. Holmes et al., 2009; Holmes et al., 2010; Klingberg, 2010; Roberts et al., 2011; Thorell et al., 2009), which would far surpass children's capacity to fully apply their attentional resources. By contrast MeeMo sessions provided children with a more intensive six minute training period on each session; long enough that children can maintain full engagement and maximally employ their full working memory capacity.

Motivation is the process by which effortful goal-directed behaviour is instigated and sustained (Pintrich, 1999). It is considered important for enabling the active and controlled allocation of attention and WM resources to a task (Sarter, Gehring, & Kozak, 2006). Recognising that increased motivation is positively correlated with successfully achieving on WM tasks (Dovis, Van der Oord, Wiers, & Prins, 2011), it is imperative that children are motivated to fully engage and employ their WM to its fullest capacity during training. A central prerequisite for a successful educational experience is a social presence (Garrison, Anderson, & Archer, 2000), which often increases children's enjoyment and motivation in activities (Anderson, 2005). While the latter is not achievable through solitary computerised programmes, it is a central feature of MeeMo. The social element of MeeMo also allows for continual sensory feedback from their partners facial, gestural, and postural expressions, serving as a powerful reinforcement to maintain attentional effort and attention (Davidson, Scherer, & Goldsmith, 2003).

The adaptive nature of WM training, where children can constantly work at a level commensurate with their individual ability, is an important feature to enable gains in WM to be achieved (Klingberg et al., 2005). Certainly, computerised programmes hold the capability to employ systematic algorithms which adapt the task difficulty to children's abilities on a trial by trial basis, thereby theoretically stretching their WM capacity to its limits. However, existing computerised programmes tend to incrementally increase difficulty after a set period of tasks, with no variation presented within each difficulty level. In contrast, a variable ratio schedule of task difficulty is a defining feature integrated throughout the MeeMo activities. This variation provides children with a range of experiences during each session, challenging them at differential levels, and increasing their engagement.

Enjoyment and other achievement related emotions are heavily influenced by children's perceived control over the anticipated outcomes from the activity (Pekrun, Frenzel, Goetz, & Perry, 2007). In particular, it has long been recognised that there are joint and synergistic effects between perceived control and levels of autonomy (Deci & Ryan, 2002). While computerised programmes are often set up and reinforced by an adult, MeeMo is independently run by the children. This autonomy and ownership can lead to higher levels of intrinsic motivation and interest (Tsai, Kunter, Lüdtke, Trautwein, & Ryan, 2008), and consequently see the application of greater effort to make progress on activities (Ciani et al., 2010).

Conclusions

The current research demonstrates the promising potential of MeeMo as an effective whole class WM training programme to increase children's WM capacity. However, as a novel programme, further research will be important to demonstrate the generalisation of these findings (e.g. differential characteristics such as age, baseline abilities, specific conditions). Accordingly, it is important that these considerations are validated through further research to assess the subsequent transference of such WM improvements on cognitive capacities (e.g. attention and fluid intelligence), achievement (e.g. literacy, comprehension and maths), as well as daily behaviours (e.g. those relating to ADHD symptomologies and emotional regulation). In particular, when evaluating these areas, it will be important to utilise a longitudinal design that can capture the differential latency periods for any such effects.

Recent research has shown that WM can be meaningfully increased through explicit, systematic and adaptive training techniques. The present research extends upon this to show

how a practical whole-class WM training programme can provide schools with an exciting prospect to not just teach to children's underlying capacity, but to actively increase their learning capacity. If effective WM training can be made accessible to all, then it holds the potential to increase every child's capacity to learn and achieve.

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Figures and Tables

Overview of Programme

- Uniquely developed as a practical, whole-class working memory training programme.
- Designed as a game to make it an engaging and enjoyable experience for children to use.
- Uses cards which display a question and instructions on the front, and an answer on the back.
- Children work in pairs, taking it in turns to be either:
    - The Questioner who asks the questions and checks the answers.
    - The Thinker who listens to the question and provides an answer.
- Five WM activities (one for each day of the week), thereby facilitating the ease of programme use, and increasing children's engagement. Each activity is used on the same day each week (e.g. Group Up – Monday, Location, Location – Tuesday).
- Three difficulty levels (easy, medium and hard) for each activity, accommodating the range of WM abilities in the class.
- Employs a multi-factorial, variable ratio of task difficulty within each difficulty level to stimulate engagement, theoretical effectiveness and meta-cognitive awareness.

Class Implementation

- Used daily for a six week period.
- Six minutes for each individual session, after which children changeover roles (Questioner / Thinker).
- Children set up and run MeeMo by themselves, which is overseen by the teacher.
- Total class session length is approximately 15 minutes a day.

Children's Process

- The Thinker receives real-time feedback by collecting cards when they achieve a right answer, and have the option to repeat questions when they recall an incorrect answer
- The Thinker's progress is visually tracked in a Personalised Monitoring Booklet.
- Children can select their own difficulty level (easy, medium and hard) on each activity.

Figure 1: Key features of MeeMo working memory training programme

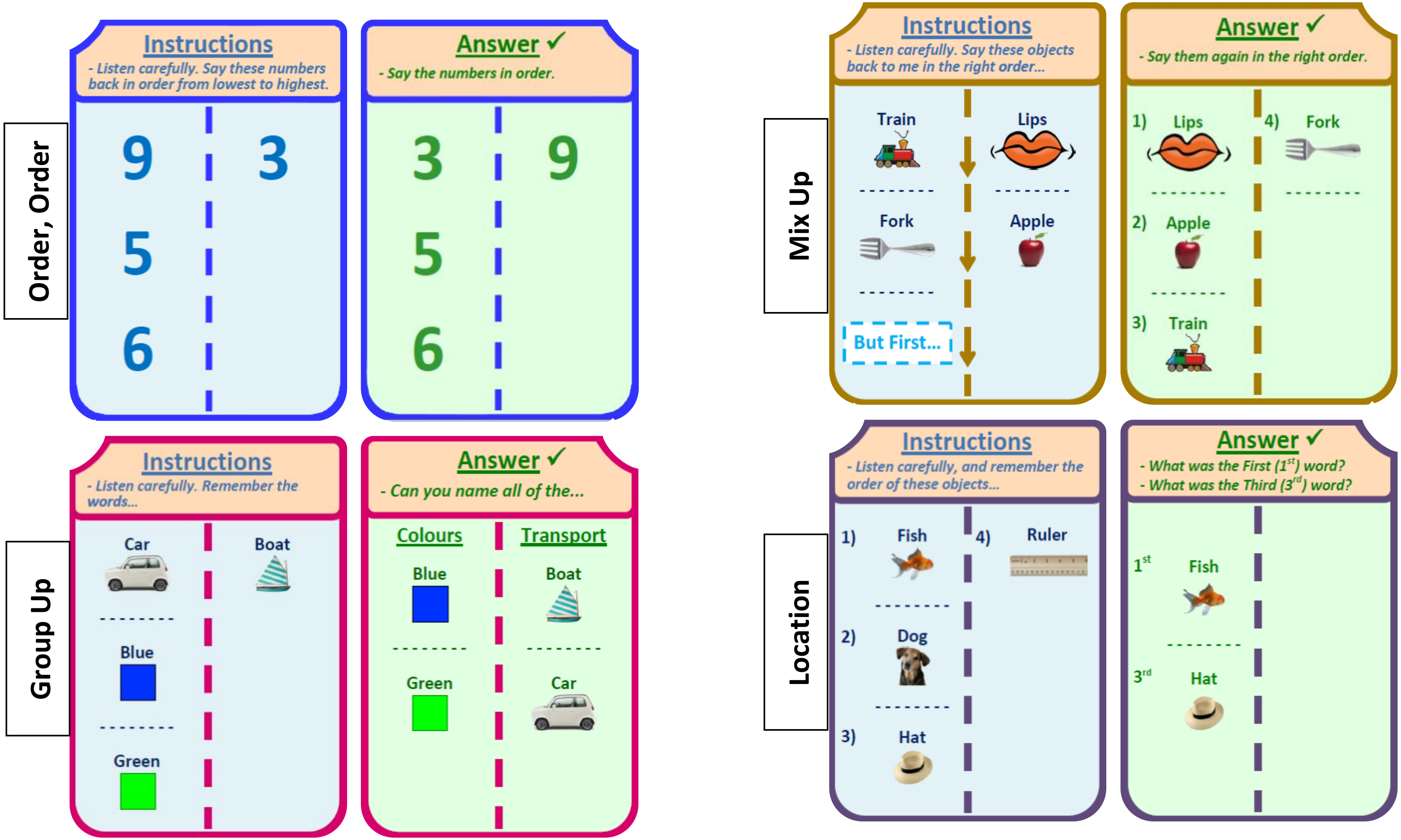
Figure 2. Evaluation of outcomes research design.

Table 1. Effects of WM training programme on WM assessments.

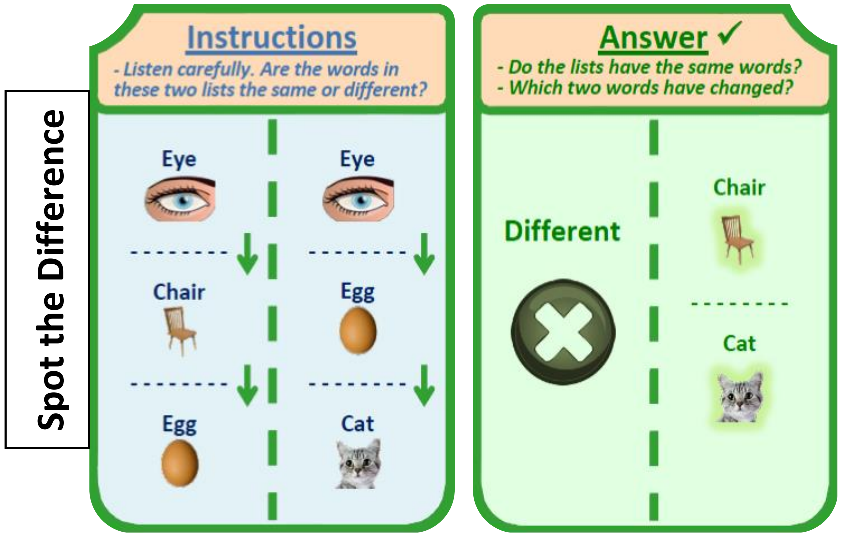
Assessment	**Pre-training (T1)** $\bar{x}$ (SD)	**Post-training (T2)** $\bar{x}$ (SD)	**Follow-up (T3)** $\bar{x}$ (SD)	**T1-T2** $\bar{x}_{diff}$ (η_p^2)	**T1-T3** $\bar{x}_{diff}$ (η_p^2)	**T2-T3** $\bar{x}_{diff}$ (η_p^2)
Verbal - STM	103.96 (6.69)	113.75 (6.9)	116.88 (7.35)	**9.79* (0.65)**	**12.92* (0.71)**	**3.13* (0.17)**
Verbal - WM	102.33 (5.53)	112.54 (4.31)	115.29 (4.82)	**10.21* (0.36)**	**12.96* (0.56)**	2.75 - -
Visuo-spatial - STM	99.88 (5.21)	104.42 (5.48)	103.17 (6.44)	4.54 - -	3.29 - -	-1.25 - -
Visuo-spatial - WM	104.08 (5.26)	109.96 (4.88)	109.38 (4.23)	**5.88* (0.26)**	**5.30* (0.19)**	-0.58 - -

* p < .05. Effect sizes (η_p^2) are reported for each significant difference.

Appendix A. Examples of Each WM Training Activity



Appendix A. Examples of Each WM Training Activity Continued.



*scale 2:3

Appendix B. Photographs of the WM Training Resources

Design Of The Cards

Illustrating the size and shape, internal and external design of the cards. The cards are grouped in sets of 10s and held within appropriately sized plastic wallets. There were a total of 4,500 cards in the MeeMo programme, thereby enabling every child in the class to simultaneously train together.