

THE EFFECT OF IMPROVED AUTOMATICITY OF BASIC NUMBER SKILLS ON PERSISTENTLY LOW-ACHIEVING PUPILS

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This research report summarises the results of an exploratory teaching program in a primary and secondary school in rural New South Wales, Australia, focused on improving basic mathematics skills. Pupils, aged 11 to 13 years, identified as consistently low-achieving in Mathematics were targeted. The program ran for approximately twenty-five weeks with pairs of pupils involved in five thirty-minute sessions per fortnight. Results of the program indicate that these pupils were able to decrease significantly their average response times needed to recall number facts. The results also showed that by the end of the program these pupils exhibited important gains on standardised test scores as well as improvements on State-wide testing measures that were not the focus of instruction. Significantly, pupils maintained performance gains 12 months after the intervention was completed.

INTRODUCTION

Pupils who have problems with learning face a myriad of difficulties in accessing the curriculum. Those who exhibit consistent weaknesses in basic skills such as the recall of number facts are particularly vulnerable. Consequently, there is a critical need for educational researchers to investigate interventions designed to support pupils who experience such difficulties with basic academic skills.

The intervention program described in this report is referred to by the generic title *QuickSmart* because it aimed to teach pupils how to become *quick* (and accurate) in response speed and *smart* in strategy use. This teaching program sought to improve automaticity, operationalised as pupils' fluency and facility with basic academic facts in Mathematics. In terms of research, the study explored the effect of improved automaticity on more demanding mathematics tasks. The fundamental research question addressed was: Does a carefully targeted teaching program aimed at improving automaticity in basic skills free up working memory processing, thereby enabling pupils to undertake more advanced age-relevant tasks that were not part of the intervention program?

THEORETICAL UNDERPINNINGS OF *QUICKSMART*

The *QuickSmart* program brings together research conducted at the Laboratory for the Assessment and Training of Academic Skills (LATAS) at the University of Massachusetts (e.g., Royer & Tronsky, 1998) and related work from the National

Centre for Science, ICT, and Mathematics Education for Rural and Regional Australia (SiMERR) at the University of New England in Armidale, Australia. Part of the theoretical background of the project relates to the work of researchers from LATAS who developed procedures for obtaining reliable assessments of pupil performance using a computer-based academic assessment system (CAAS). Importantly, the assessment tasks used are designed and sequenced in order to help identify particular obstacles that may impede pupil learning. The techniques developed by LATAS have been used successfully as a means of diagnosing the academic problems of pupils who have specific reading and/or mathematics learning difficulties. The *QuickSmart* program has situated CAAS within a teaching approach that incorporates a focus on systematic instruction with the consistent monitoring of pupil performance. This instructional focus is particularly valuable for those pupils who meet the criteria of being ‘treatment resistant’ to usual instructional and remedial efforts/methods.

Based on analysis of the diagnostic information obtained from CAAS assessments, discussions with teachers, and other available test results, *QuickSmart* instructional interventions are tailored to strengthen each pupil’s problematic skills. The interventions are also based on a substantial body of research related to the importance of particular basic academic skills in the development of understanding of the four operations on simple and extended tasks (e.g., Ashcraft, Donely, Halas, & Vakali, 1992; Zbrodoff & Logan, 1996).

Theoretical and pragmatic considerations that point to the importance of developing automatic low-level skills in basic Mathematics underpin the *QuickSmart* intervention. First, it is generally accepted that the cognitive capacity of humans is limited and that working memory has specific constraints on the amount of information that can be processed (Zbrodoff & Logan, 1996). As such, there is good reason to expect that improving the processing speed of basic skills will free up working memory capacity that then becomes available to address more difficult mathematical tasks. Research has already indicated that the ability to recall information quickly uses minimal cognitive capacity (e.g., McNamara & Scott, 2001). Another reason why the automatic performance of low-level academic skills is of prime importance is that it allows for small decreases in response time to accrue across subtasks, again freeing up working memory (Royer, Tronsky, & Chan, 1999). There is evidence that in basic Mathematics, a pupil’s lack of automaticity can result in a reduced ability to solve problems and understand mathematical concepts (Gersten & Chard, 1999).

In summary, *QuickSmart* is a theory-based intervention that supports basic skill development for chronic low-achievers in Mathematics. Specifically, this research implemented instructional program aimed to increase pupils’ understanding and speed of recall of basic number facts by freeing up working memory capacity within the context of a personalised learning environment where pupils are withdrawn in pairs from their normal class.

METHODOLOGY

The *QuickSmart* intervention delivered instruction five times per fortnight for approximately twenty-five weeks to pupils with consistent and long-term difficulties in basic Mathematics. Important to the development and implementation of the *QuickSmart* program was close collaboration with the parents, teachers, support teachers, and principals of the participating schools.

Design The study was designed as a quasi-experiment to measure the effect of increased accuracy and automaticity in basic Mathematics on more difficult mathematics questions for middle-school pupils (11-to-14 year olds) who exhibit long-term poor performance in Mathematics. Measures of improved mathematical ability were operationalised by pupil's performances on more difficult mathematics questions as provided by Australian designed standardized tests. These data were gathered before and after the intervention for the target pupils, as well as for comparison groups of same-age peers. In addition, qualitative data from sources such as interviews and field notes were collected throughout the research.

Participants A total of 12 pupils, six boys and six girls, enrolled in Years 5 or 7 from two schools in a regional district of New South Wales, were selected to participate in the *QuickSmart* Mathematics program. Within this group, three primary school pupils, and one high school pupil, were identified as Indigenous Australians.

Year 5 participants (11 year olds) All pupils in a mixed-ability class were individually assessed on basic academic skills. Based on this assessment information, and in consultation with the class teacher, six low-achieving pupils were selected. The remainder of the pupils in the class became the comparison/control group.

Year 7 participants (13 year olds) In this case the pupils in the secondary school were selected by the Head Mathematics Teacher using the criteria (i) the pupils experienced learning difficulties in basic Mathematics, (ii) performed within the lowest two bands on the State-wide Year 7 screening tests; (iii) had not shown improvement as a result of other school-based intervention or remedial programs, and (iv) attended school regularly. As a means of having a control/comparison group, four Year 7 pupils who were either average or high achieving were also identified. These comparison pupils were assessed using the same materials as the intervention group at the beginning and the end of the *QuickSmart* program.

Procedures The project plan consisted of three phases – an initial assessment, the *QuickSmart* intervention program, and a final assessment phase. The *QuickSmart* program ran for twenty-six weeks for Year 5 pupils and twenty-four weeks with the Year 7 pupils. All pupils participating in the *QuickSmart* intervention were withdrawn from their classes in pairs for five half-hour lessons spread across each fortnight with the same instructor. Where possible, the pairings of pupils matched individuals with similar instructional needs in basic Mathematics. The *QuickSmart* intervention focused on a variety of practice and recall strategies to develop

understanding and fluency with basic numeric skills. Each lesson involved at least four components, namely:

- revision of the previous session,
- a number of guided practice activities featuring overt self talk and the modelling of strategy use,
- discussion, clarification and practice of memory and retrieval strategies,
- games and worksheet activities that focused on timed independent practice activities.

Observations and information gained from questioning pupils about their strategy use formed the basis of instructional decision-making and individualization. Information was also derived from lesson activities.

Additionally, CAAS assessments were completed at the end of most lessons. These provided on-going data related to pupils' levels of accuracy and automaticity in basic skills. Pupils evaluated their own learning through recording information obtained during each instructional session and using this information to identify progress and to help set realistic future goals for their achievement. Of importance was that the CAAS assessments represented a random selection of 20 items within different categories drawn from an extensive database of questions.

In order to develop transfer of learning, the *QuickSmart* intervention emphasized knowledge that could be used in classroom and other real-life settings. As well, there were attempts to link *QuickSmart* content to current classroom curriculum whenever possible.

Instruction in the *QuickSmart* program was organised into units of work of three-or-four-weeks duration with a focus on a specific set of mathematics facts. These focus facts were sets of related number facts ranging in difficulty from combinations of numbers that equal 10, to 12 times tables. It is important to note that focus facts for each unit also contained related facts such as $3 + 7 = 10$, $30 + 70 = 100$; $2 \times 12 = 24$, and $\frac{1}{2} \times 12 = 24$. This approach helped to facilitate pupils' observations and understandings about the reciprocity of relationships between numbers.

Typically, the lessons began with a review of focus facts starting with those already known, and then moving on to those facts that the pupils still needed to understand and remember. Teacher-led discussion and questioning about the relationships between number facts, and ways to recall them merged into simple mathematics fact practice activities often revolving about highly focused games. These games were developed to complement each set of focus facts and allowed pupils to review and consolidate their learning in a motivating way. Timed performance activities were also used to assist pupils in developing automatic recall. In the last phase of the lesson, pupils practised on carefully selected worksheets that were closely related to the lesson content, before concluding with a brief CAAS assessment.

A feature of the lessons throughout the program was both structured and incidental strategy instruction. The aim of this strategy approach was to move pupils from

relying on slow and error prone strategies, especially count-by-one strategies, to using more sophisticated and efficient strategies, including automatic recall.

Dependent Measures Data on dependent measures were collected before, during and after the *QuickSmart* intervention. Results came from four sources: CAAS, standardized tests, qualitative data, and comparison data. The results presented in this brief report focus on CAAS assessment data, and standardised test results, as well as opportunistic data available from the State-wide Year 5 Basic Skills Tests. Detailed analysis and discussion of the qualitative data is currently under preparation.

Assessments using the CAAS provided data on accuracy and automaticity of basic Mathematics. Five sub-tests of CAAS were used in this phase of the research. These were number naming of two digit numerals; addition (single plus single digit, and single plus double digit); subtraction (single and double digit numerals less than 20); triple addition (three numerals less than 20, appearing as $4 + 8 + 3$); multiplication facts (to times 12); and related division facts.

Standardised Tests were used to help assess pupils' abilities to engage in more difficult mathematics activities. These tests were administered before and after the intervention. The Progressive Achievement Tests (ACER) were selected to measure this important variable. Specifically, parallel forms of the Progressive Achievement Tests in Mathematics (PATMaths) (ACER, 1997) were administered to Year 5 (Test 1A) and Year 7 (Test 2A) pupils before and after the *QuickSmart* intervention. These tests measure mathematics performance across the range of National Profile strands – number, space, measurement, and chance and data.

RESULTS

The data from pupils' information retrieval times on CAAS tasks, their standardised test scores, and opportunistic data from State-wide Year 5 Basic Skills Tests were all supported by rich observational and field notes. Although not discussed here, these qualitative insights were important in developing profiles of pupils as learners and descriptions of the cognitive obstacles that prevented their success with basic Mathematics.

Data from the Computer-Based Academic Assessment System The CAAS system recorded data relating to retrieval times and accuracy levels on all tasks for all pupils on all occasions. The analyses presented in this section are based on the graphical representation of pupils' information retrieval times similar to Figure 1.

The graph in Figure 1 shows that the average information retrieval times of pupils decreased over time. For example, the Year 5 pupils were able to answer accurately addition sums in an average time of 1.7 seconds by the end of the *QuickSmart* program. At the beginning of the intervention, these same pupils took up to an average of 5.2 seconds to calculate each addition task.

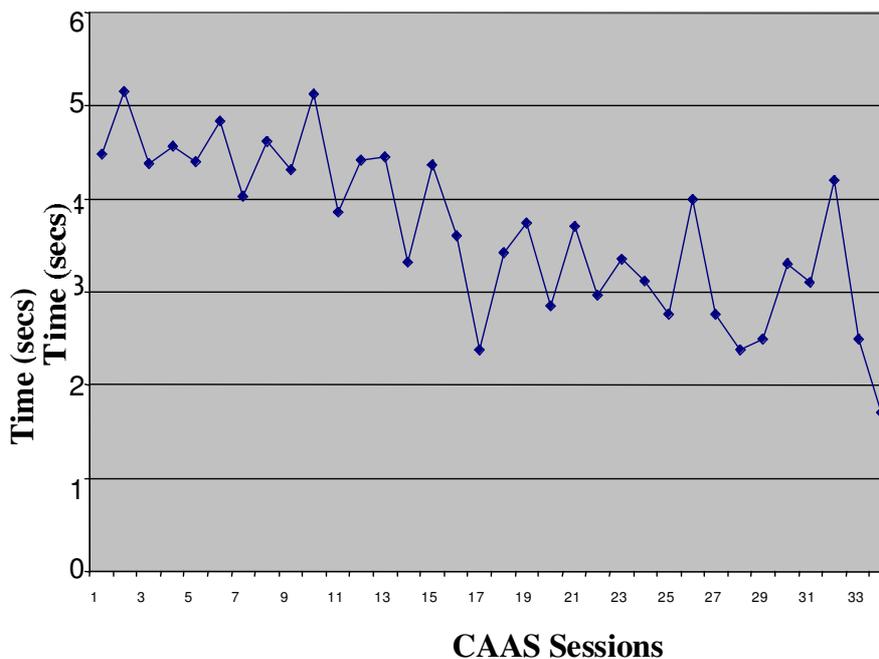


Figure 1: Year 5 Addition Averages

The improvement in retrieval times for Year 7 Mathematics pupils who completed the CAAS multiplication tasks was also dramatic. At the beginning of the program pupils took an average time of approximately 2.6 seconds to respond to each multiplication example. By the end of *QuickSmart*, the average time was more than halved to 1.15 seconds.

A further filter through which to view the results of the intervention program is provided by comparing groups of pupils' response times before and after the intervention. Pupil's *t*-tests (two-tailed with unequal variance) were applied to detect statistical differences between intervention and comparison groups, and paired *t*-tests (two-tailed) were used to detect differences within groups (before versus after). These analyses indicate that the *QuickSmart* intervention was effective in assisting pupils to achieve results comparable to those of their same-age peers. In two out of three mathematics sub-tests of the CAAS there were significant differences between the participants and comparison pupils before the intervention. After the intervention no significant differences were found between the groups' response times. This finding supports the claim that *QuickSmart* can bring pupils 'up to speed' in comparison to their peers on basic mathematics tasks.

Standardised Test Scores Although it is accepted that improvement on standardised measures is hard to achieve through intervention research, all of the Year 5 pupils and five-of-the-six Year 7 pupils increased their post-test percentile rank scores. Individual improvements of up to 63 percentile points were noted.

T-test results indicate that the Year 5 and 7 *QuickSmart* pupils' post-test scores were uniformly higher, at the .05 level of significance, than their pre-test scores ($t = 2.49, p < .05$). These results can be interpreted as support for the hypothesis that increased

accuracy and automaticity in basic academic skills results in improvements in undertaking more difficult mathematics tasks.

Opportunistic data were also available from the State-wide Year 5 Basic Skills Test. Results indicate that for the first time since this State-wide program of testing began, no pupils in this particular primary school were placed in the lowest band for Mathematics. In fact, only one Year 5 pupil was in the second lowest achievement band (Band 2) while two pupils achieved in the second highest band (Band 5).

Of the six pupils participating in the *QuickSmart* program, three had also been pupils at the same school during Year 3. Consequently, these pupils' State-wide Year 3 Basic Skills Test results were available to the researchers. This information is summarised in Table 1. All these pupils showed improvement in Mathematics greater than Literacy and the state average of 6.5 growth points. The *QuickSmart* Mathematics group scored an average of 9.4 growth points on the Basic Skills Test for Mathematics, compared to an average of 6.5 points for their Literacy scores.

<i>QuickSmart</i> Mathematics PUPILS				
	Year 3	Year 5	Band Year 5	Growth Score
<i>QuickSmart</i> Mathematics Pupil 1				
<i>BST</i> Literacy Results	47.4	54.2	4	6.8
<i>BST</i> Mathematics Results	40.2	49.9	3	9.7
<i>QuickSmart</i> Mathematics Pupil 2				
<i>BST</i> Literacy Results	51.8	55.5	4	3.7
<i>BST</i> Mathematics Results	43.6	51.6	3	8.0
<i>QuickSmart</i> Mathematics Pupil 3				
<i>BST</i> Literacy Results	48.8	57.7	5	8.9
<i>BST</i> Mathematics Results	53.4	63.9	5	10.5

Table 1: Basic Skills Results (Growth Average for the State is 6.5 pts)

CONCLUSION

The *QuickSmart* intervention made a marked difference to the mathematics performance of those pupils who participated in the program. The most marked differences occurred for the Year 5 pupils although the Year 7 pupils also showed statistical significant improvements.

A follow-up study with the same pupils found they did not regress over a period of one year after the intervention program was completed. Hence, these pupils were able to maintain the gains they made. Importantly, this maintenance of performance was sustained across all the mathematics tasks tested by the CAAS system.

Because the *QuickSmart* intervention has a strategy orientation to improving pupils' basic academic skill performance, it moves away from addressing academic problems through 'busy' unsequenced worksheet practice. Instead, it offers an alternative based on supporting pupils to learn to "trust their heads" by encouraging pupils to discard effortful strategies hence freeing up the demands basic Mathematics has on their working memory. As such, the *QuickSmart* program represents a fourth-phase intervention model for offering a new hope for supporting persistent low achievers in Mathematics. This fourth phase is appropriate after initial teacher instruction (Phase 1), teacher remediation in class (Phase 2) and typical in-class remediation by a support teacher (Phase 3) have proven unsuccessful.

In the *QuickSmart* program there are four main themes:

- there is an emphasis on self-regulation, metacognition and self-esteem, with the goal of increasing independence in learning;
- there is extended practice in the application of understanding and strategy use;
- pupil progress is regularly monitored and feedback given; and
- positive reinforcement is provided and initially this needs to be extrinsic, but intrinsic motivation is the long-term goal.

Future research will explore how these key themes relate in helping pupils confront their learning obstacles and whether any one of these points is most significant in leading to improved learning outcomes. Also needed from research is information on whether there are optimal years of schooling in which to offer *QuickSmart* to pupils with mathematics learning difficulties, and to explore, more deeply, relationships between automaticity of basic mathematics skills and working memory capacity.

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