INTERVENTION FOR MIDDLE SCHOOL STUDENTS WITH POOR ACHIEVEMENT IN MATHEMATICS

Shirley M. Yates, Michelle Lockwood

Christian Brothers College, Adelaide, South Australia

Poor mathematics achievement in middle school students is evident in many countries. While some of the difficulties can be attributed to student related factors, there is considerable evidence that computational automaticity is essential for mathematics achievement. A QuickSmart (QS) mathematics intervention program was trialled with a group of students in Grades 7 and 8, matched with a control group of similar underachieving classmates. A statistically significant decrease in mean response latencies was found for QS participants after lessons in multiplication only. Significant differences were also evident between the pre and post scores of the two groups on a standardised test of mathematics. This study confirms and extends previous findings of the efficacy of mathematics intervention for underperforming middle school students.

INTRODUCTION

Poor achievement in mathematics has been investigated in numerous studies in many countries in relation to student factors such as cognitive difficulties, memory, attention, motivation, anxiety and self efficacy. Other studies have focussed on teaching methods and curriculum issues (Vaughn, Bos & Schumm, 2000), with dyspedagogia (Westwood, 2004) or poor teaching cited as having a significant impact on student failure in basic mathematics. While the development of mathematical reasoning depends on students learning appropriate facts, concepts, strategies and beliefs, lack of procedural knowledge of the basic operations for addition, subtraction, multiplication and division is *the most obvious obstacle to academic success in mathematics* (Mayer, 2006, p. 65). The development of computational fluency or the speed with which students can retrieve or calculate answers to simple mathematics problems is a prerequisite to mathematics achievement at all levels (Arroyo, Royer & Woolf, 2011). Cognitive psychologists have established a clear relationship between the development of basic computational automaticity and complex mathematical problem solving skills (Tronsky & Royer, 2002). A multiplicity of studies have found that being able to produce answers to basic number facts rapidly and accurately reduces the load on the working memory and *it is this saving that is a key factor in being able to develop more complex problem solving abilities* (Tronsky & Royer, 2002, p. 118).

A recent report on Australia's performance in the 2012 *Programme for International Student Assessment* (PISA) has raised considerable concerns about the significant decline in the mathematical literacy of 15 year old students in Australia in general and South Australia in particular (Thomson, De Bortoli & Buckley, 2013). Between PISA 2000 and PISA 2012 Australia's mean mathematical literacy performance dropped

2014. In Nicol, C., Oesterle, S., Liljedahl, P., & Allan, D. (Eds.) Proceedings of the Joint Meeting of PME 38 and PME-NA 36,Vol. 5, pp. 393-400. Vancouver, Canada: PME.

significantly from fifth to 19th place, with the decline most evident in the mean increase in the proportion of low performing students and decrease in top performers. South Australia has experienced one of the largest deteriorations, with the decrease of 46 score points equivalent to more than a year of schooling and where 12 per cent more students did not reach base Level 2 in 2012 (Thomson, Hillman & De Bortoli, 2013). Significant declines in South Australia are also evident in Grade 8 students in the *Trends in International Mathematics and Science Study* (TIMSS) from 1995 to 2011 (Thomson, Hillman & Wernert, 2012). Results from TIMSS 2011 have highlighted a substantial 'tail' of underperformance in mathematics, with 11 per cent of Australian students not even achieving the Low international benchmark (Thomson et al., 2012).

Students' poor performance in mathematics poses significant pedagogical issues for schools but particularly for middle school teachers who are caught in a "back to basics" dilemma (Yates, 2009a). Over time underachieving students fall increasingly behind their normally achieving peers and by the eighth year of school can be up to five years behind their average achieving peers (Pegg & Graham, 2007). Many students in the middle school years have to expend considerable effort to work on lower level component skills they have encountered many times before (Hattie & Yates, 2014). Practice is essential for students to gain automaticity of basic skills in mathematics content areas (National Mathematics Advisory Panel, 2008), but in middle school classrooms there is much less time and opportunity to develop skills that should have acquired in the early elementary grades (Carr, Taasoobshirazi, Stroud & Royer, 2011).

THE PRESENT STUDY

This research report is part of a larger longitudinal study of student mathematics achievement, self efficacy, anxiety and learned helplessness in a non-government, single sex, elementary and secondary school for boys in Adelaide, South Australia. The *Progressive Achievement Tests in Mathematics Plus* (PATM) (Australian Council for Educational Research, 2010) were administered online to students in Grades 3 to 10 in March (Time 1) (T1) and November (Time 2) (T2), 2013. At T1 students completed the PATM test for their respective previous Grade level and at T2 their current Grade. At T1 a 'tail' of underperformance (Thomson et al., 2012) was most evident in Middle School students, with 33 (53%) of 63 Grade 7 boys and 33 (24%) of 140 Grade 8 boys scoring in the percentile rank range of 1-19 (-1 standard deviation) (SD). A further nine students in Grade 7 and 17 students in Grade 8 scored in the 20-30 percentile rank range. The poor achievement of some students could be accounted for, at least in part, by a verified learning disability or difficulty, but individual PATM profiles for the remaining students indicated poor performance in the numeracy strand.

The school decided to trial the research-based *QuickSmart* (QS) mathematics intervention for the latter group as the program is designed to improve low achieving middle school students automaticity with addition, subtraction, multiplication and division over 30 weeks (Pegg, Graham, & Bellert, 2005; Graham & Pegg, 2010). Previous studies have shown QS participants gained on average two to three years progress (effect size 0.49 - 0.80) measured from PATM pre to post test scores (Pegg & Graham, 2009) and improved on measures of response speed and accuracy compared with average achieving (Bellert, 2009) or high achieving same-age non-participants (Graham, Bellert, Thomas & Pegg, 2007). The present quasi-experimental study used pairs of underperforming students in the same mathematics classrooms to compare pre and post scores on the PATM. Further, the comparisons between QS participants and the paired classmates were undertaken after the completion of the first part of the QS program on multiplication rather than at its conclusion as in the previous studies. Response automaticity and accuracy were examined for both groups prior to QS and for QS students at the completion of the multiplication section of the intervention.

AIMS

1. To investigate the QS intervention program for middle school students with poor achievement in mathematics; and
2. To compare the performance of students participating in the QS program with their paired classmates who received classroom instruction in mathematics only.

METHOD

Participants

Eight Grade 7 students and 12 Grade 8 students with PATM scores in the 1-30 percentile rank range at T1 were nominated by their mathematics teachers on the basis of their attendance, behaviour and poor performance on the PATM numeracy subscale. The 20 students were paired within their mathematics classes, with one student from each pair assigned to the QS group and the other to a control group. QS students were then grouped in pairs by Grade level for the delivery of the program. Students ranged in age from 12.3 years to 13.11 years with a median age of 13.3 years.

The *QuickSmart* Mathematics Intervention Program (Graham et al., 2007)

The multiplication section of QS was delivered to pairs of students in three 30 minute lessons per week over a mean of 16.5 hours.

Procedure

In Terms 3 and 4 a mean of 33 lessons, focussed on multiplication only, were delivered to the 10 pairs of designated QS students by a trained teacher aide, supervised by a registered teacher. These lessons were additional to their classroom instruction in mathematics. Each QS lesson consisted of 5 minute sections of a knowledge and understanding check, flashcards, speed sheet challenge of multiplication number facts, independent work sheet/strategy development, assessment and games. Response speed and accuracy was measured separately for each student in each lesson with the *Cognitive Aptitude Assessment System* (CASS) computer package (Royer, 1996) which is based on the Baddeley model of working memory (Tronsky & Royer, 2002). The CASS times student verbal responses via a microphone to randomised number sentences on a computer screen while the aide scores each response for accuracy.

Results are averaged and graphed automatically, providing each student with feedback to monitor his performance immediately and over time. QS and control students were tested with the CASS prior to the commencement of the intervention in Term 3, but thereafter students in the control group received five 40 minute mathematics lessons per week only. Numeracy achievement data from the *National Assessment Program – Literacy and Numeracy* (*NAPLAN*) administered annually in Australia to students in Grades 3, 5, 7 and 9 was available from 2013 for Grade 7 and 2012 for Grade 8.

Analyses

QS and control group students initial CASS averaged response time and accuracy scores, PATM scaled scores at T1 and T2 and NAPLAN numeracy logit scores were entered into a Statistical Package for the Social Sciences (SPSS) computer program. Speed scores were also entered for the final multiplication lesson for the QS students. The statistical analyses were conducted with nine QS students (program attrition of one boy in Grade 8) and nine control students (incomplete data for a Grade 7 boy).

RESULTS

The median accuracy score measured by the CASS for both groups was 88% prior to the intervention and 100% for QS students at the completion of the multiplication lessons. Initial CASS speed scores for QS students, shown in Figure 1, ranged from 1.77 - 4.80 seconds, with a mean of 2.78 secs and SD of 0.96. Control group scores ranged from 1.50 - 4.79 seconds with a mean of 2.64 (SD = 0.93). Analysis of Variance (ANOVA) revealed no statistically significant differences between the mean speed of the two groups before the QS began [F (1,16) <1]. However, there was a statistically significant relationship between QS students' mean speed score prior to and at the end (Mean = 1.21 secs, SD 0.34) of the multiplication lessons [F (1, 8) = 39.28, p<0.001].

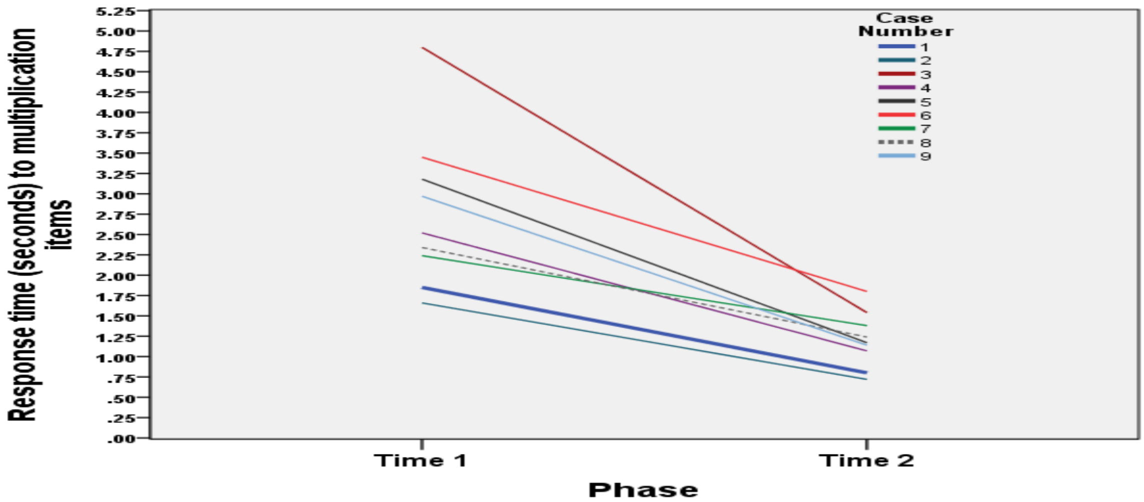

Figure 1: Speed scores for QS students prior to and after the multiplication intervention

Although students were administered different pre and post tests their scaled scores can be validly compared as PATM tests are scaled on a single interval scale of mathematics achievement through the RASCH measurement model (ACER, 2010).

The effect of prior knowledge on PATM scores and QS intervention was tested by using students' NAPLAN scores as a covariate. While NAPLAN scores predicted students' PATM score at T1, it did not serve as a covariate for the treatment effect.

The difference between the mean PATM scaled scores presented in Figure 2 for QS students at T1 of 53.2 (SD = 2.9) and 49.9 (SD = 2.6) for the controls was statistically significant ($p< 0.005$). The difference between the mean PATM scaled scores at T2 of 55.58 (SD = 3.3) for QS and 51.0 (SD = 4.0) for controls was also statistically significant ($p< 0.001$). Covariance analysis which controls for the baseline score at T1 showed the group effect remained significant [$F\ (1,15) = 6.5\ p< 0.022$], with the achievement of the QS students increasing more over time compared with the control group. Repeated measures interaction approached significance [$F(1,15)=6.5, p<0.06$].

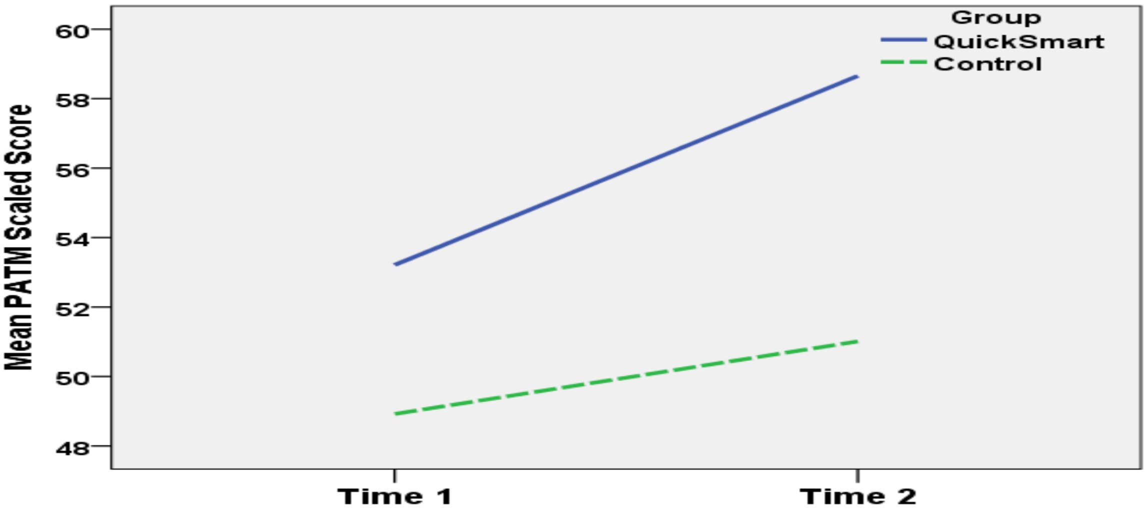

Figure 2: PATM scaled scores for QS and control students at T1 and T2

DISCUSSION

Developing automaticity in cognitive processing is a major goal in mathematics for students in the early elementary grades. Failure to acquire basic mathematics skills by the middle school grades has significant consequences for students who have to employ effortful and costly mental strategies to solve tasks that essentially require low level knowledge (Hattie & Yates, 2014). Lack of automaticity was evident for both groups of students in the initial CASS scores where their mean response latencies were reasonably accurate but slow. There was also considerable variability in the response speeds of both QS and control group students, shown in Figure 1 for the QS group. The statistically significant decrease in the mean response latency for the QS group by the end of the multiplication lessons is an important finding as it extends previous studies which have reported students to be quicker in fact retrieval and smarter at strategy use by the conclusion of the QS intervention (Bellert, 2009; Pegg & Graham, 2009).

In relation to the second aim of the study, students' performance on PATM at T1 was predicted by their numeracy achievement as measured by the NAPLAN. Both the PATM and NAPLAN numeracy test were administered under timed conditions so it is likely that lack of fluency would have influenced the performance of both groups (Arroyo, Woolf, Royer, Tai & English, 2010). Previous studies have found speed of retrieval of mathematics facts to be a significant predictor of middle school students' test performance (Royer, Tronsky, Chan, Jackson, & Marchant, 1999).

The statistically significantly difference in PATM scores between QS participants and control group at T1 is difficult to explain. However, the significant increase in the gap between the achievement of the QS and control groups at T2 is a notable finding which can be attributed to the QS intervention., There was no statistically significant difference in mean CASS response latencies between the two groups prior to the intervention, the effect of baseline performance on PATM was controlled for in the covariance analysis, QS and control students were paired within their respective Grade 7 or 8 classrooms and received the same number of mathematics lessons each week, at the same time, from the same teachers, with the same textbooks and over the same time frame. Further, although the key focus of the additional lessons received by the QS group was to improve their understanding and speedy recall of basic multiplication facts, through the rehearsal of more sophisticated and efficient strategies which foster automatic recall (Bellert, 2009), the increase in their PATM scores is also evidence of generalisation to learning in other domains of mathematics. This finding extends evidence from a previous study in which middle school students had significantly higher PATM raw scores after completing the QS program in the four basic processes (effect size = 0.65) (Bellert, 2009). The current finding also raises the interesting research question of whether it is just as efficacious to administer the multiplication section of the program only rather than in its entirety.

With respect to Aim 1 from the school perspective, the implementation of the intervention program in the middle school grades has considerable response costs associated with the purchase of the QS program, annual licensing fee, teacher aide and supervising teacher training and allocation of teaching time and space within which to operate the program. Further, QS participants have to be withdrawn from three lessons every week which affects their participation in their other subject areas. QS lessons were timetabled to occur on a Monday, Wednesday and Friday to provide the opportunity for spaced rather than massed practice (Carpenter, 2014), but it is interesting to note that over Terms 3 and 4 (of 10 and 9 weeks duration respectively) students completed only a mean of 33 QS lessons over 16.5 hours. While some of the discrepancy can be explained by the time taken with the initial CASS testing with both groups of students and student absence from school, it was noted on several occasions that opportunities for QS lessons to occur were affected by school sanctioned activities such as assemblies, excursions, sports days and other events.

These costs of implementing an intervention in the middle school grades have to be considered against the long term effects of not providing any intervention. There is considerable research evidence that students' ability to retrieve basic number facts will not improve across the elementary school years without intervention (Gersten, Jordan & Flojo, 2005). Further, speed of retrieval is a significant predictor of students' achievement on mathematics tests throughout their secondary schooling and beyond (Royer et al., 1999). While the effects of the numeracy intervention on student work samples, self efficacy, anxiety and learned helplessness in mathematics (Yates, 2009b) will be considered at the completion of the trial of the QS program in 2014, the results thus far nevertheless indicate quite strongly that significant positive changes are evident in response latencies, accuracy and achievement in mathematics when students are provided with the knowledge of and opportunities to practice more efficient and effective basic skills and strategies in a supportive small group environment with motivating feedback.

Acknowledgements

Assistance from Mrs Pamela Holmes and John Santini is gratefully acknowledged.

References

Arroyo, I., Royer, J. M., & Woolf, B. P. (2011). Using an intelligent tutor and math fluency training to improve math performance. *International Journal of Artificial Intelligence in Education*, *21*, 135-152.

Arroyo, I., Woolf, B. P., Royer, J. M., Tai, M., & English, S. (2010). Improving math learning through intelligent tutoring and basic skills training.. In V. Aleven, J. Kay, & J. Mostow (Eds.), *ITS 2010, Part 1, LCNS 6094*. Berlin, Heidelberg: Springer-Verlag.

Australian Council for Educational Research. (2010). *The Progressive Achievement Tests in Mathematics Plus*. Melbourne: ACER.

Bellert, A. (2009). Narrowing the gap: A report on the QuickSmart mathematics intervention. *Australian Journal of Learning Difficulties*, *14*(2), 171-183.

Carpenter, S. K. (2014). Spacing and interleaving of study and practice. In V. A. Benassi, C. E. Overson, & C. M. Hakala (Eds.), *Applying science of learning in education: Infusing psychological science into the curriculum* (pp. 131-141). Washington, DC: Division 2, American Psychological Association.

Carr, M., Taasoobshirazi, G., Stroud, R., & Royer, J. M. (2011). Combined fluency and cognitive strategies instruction improves mathematics achievement in early elementary school. *Contemporary Educational Psychology*, *36*, 323-333.

Gersten, R., Jordan, N. C., & Flojo, J. R. (2005). Early identification and interventions for students with mathematical difficulties. *Journal of Learning Disabilities*, *38*(4), 293-304.

Graham, L., Bellert, A., Thomas, J., & Pegg, J. (2007). QuickSmart: A basic skills intervention for middle school students with learning difficulties. *Journal of Learning Disabilities*, *40*, 410-419.

Graham, L., & Pegg, J. (2010). Hard data to support the effectiveness of QuickSmart numeracy. *Learning Difficulties Australia Bulletin*, *42*(1), 11-13.

Hattie, J., & Yates, G. C. R. (2014). *Visible learning and the science of how we learn.* Abington, Oxon: Routledge.

Mayer, R. E. (2006). The role of knowledge in the development of mathematical reasoning. In R. L. Sternberg & R. F. Subotnik (Eds.), *Optimising student success in school with the* *other three Rs: Reasoning, resilience and responsibility* (pp. 59-74). Greenwich, Connecticut: Information Age Publishing.

National Mathematics Advisory Panel. (2008). *Foundations for success. The final report of the National Mathematics Advisory Panel.* Washington, DC: U.S. Department of Education.

Pegg. J. E., & Graham, L. (2007). Addressing the needs of low achieving mathematics students: Helping students to trust their heads. Keynote. In K. Milton, H. Reeves, & T. Spencer (Eds.), *Proc. 21st Conference of the Australian Association of Mathematics Teachers* (pp. 33-45). Adelaide: The Australian Association of Mathematics Teachers, Inc.

Pegg. J. E., & Graham, L. (2009). *QuickSmart intervention research program data 2001-2008 full report*. Armidale, NSW: University of New England.

Pegg. J. E., Graham, L., & Bellert, A. (2005). The effects of improved automaticity of basic number skills on persistently low-achieving pupils. In H. L. Chick & J. L. Vincent (Eds.), *Proc. 29th Conf. of the Int. Group for the Psychology of Mathematics Education* (Vol. 4, pp. 4-49). Melbourne, Australia: PME.

Royer, J. M. (1996). Cognitive assessment of reading competencies: Diagnosis and prescription. In G. D. Pyne (Ed.), *Handbook of academic learning* (pp. 199-234). San Diego, CA: Academic Press.

Royer, J. M., Tronsky, L. N., Chan, Y., Jackson, S. J., & Marchant, H. G. (1999). Math fact retrieval as the cognitive mechanism underlying gender differences in math test performance. *Contemporary Educational Psychology*, *31*, 181-266.

Thomson, S., De Bortoli, L., & Buckley, S. (2013). *PISA in brief: highlights from the full Australian report: PISA 2012: How Australia measures up*. Melbourne: ACER.

Thomson, S., Hillman, K., & De Bortoli, L. (2013). *A teacher's guide to PISA mathematical literacy*. Melbourne: ACER.

Thomson, S., Hillman, K., & Wernert, N. (2012). *Monitoring Australian Year 8 student achievement internationally: TIMSS 2011*. Melbourne: ACER.

Tronsky, L. T., & Royer, J. M. (2002). Relationships among basic computational automaticity, working memory, and complex problem solving: What we know and what we need to know. In J. M. Royer (Ed.), *Mathematical cognition* (pp. 117-146). Greenwich, Connecticut: Information Age Publishing.

Vaughn, S. R., Bos, C. S., & Schumm, J. S. (2000). *Teaching exceptional, diverse, and at-risk students in the general education classroom*. Boston, MA: Allyn & Bacon.

Westwood, P. (2004). *Learning and learning difficulties: A handbook for teachers*. Melbourne: ACER.

Yates, S. M. (2009a). The "back to basics" dilemma for middle school teachers. In R. Hunter, B. Bicknell, & T. Burgess (Eds.), *Crossing divides: Proceedings of the 32nd annual conference of the Mathematics Education Research Group of Australasia* (Vol. 2, pp. 619-625). Palmerston North, NZ: MERGA.

Yates, S. M. (2009b). Teacher identification of student learned helplessness in mathematics. *Mathematics Education Research Journal*, *21*(3), 86-106.