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Early Mathematics Learning Assessment

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Abstract

Mathematics, as a discipline, is abstract. Its importance in education and life is axiomatic. Therefore, mathematical concepts need to be nurtured from an early age. Activities related to mathematics, in the initial years of a child's education, would play a key role in laying the foundations of the subject. It has been amply demonstrated through researches that children's competency level at the beginning of formal schooling is important for their career and life. Literacy and numeracy skills underpin workforce participation, productivity and economy, and hence, impact social and health outcomes. Building mathematical skills is essential for a first grader's learning process as it determines one's academic success. The assessment of children in years before schooling and the first year of school has been, traditionally, informal. Further, assessment of children's mathematical skills at this level is uncommon compared to social, emotional and physical assessment. However, there are contexts, where reliable, valid and standardised data from assessment in mathematics are required. This paper reviews the assessment processes and techniques originally developed for early mathematics.

Introduction

World leaders and educationists emphasise the significance of education in the early grades, teachers are yet to be provided with adequate information or training on assessment at early grades. Thus, reasonably common, clear and actionable learning metrics, particularly, in the early grades, continue to elude this sector. This is more so in developing countries, where the goal of getting all children enrolled in schools and ensuring that they complete their primary education is the priority. The search for improved metrics and measurement of learning

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increased only during the post–1990s all over the world.

Mathematical skills are essential for adults — employed or unemployed — to function successfully in everyday life and profession. The importance of mathematical skills continues to increase as societies and economies move towards more technologically advanced activities.

Therefore, it is important that learners gain fundamental understanding of basic numeracy skills at school. The lack of it puts them at a risk of not being able to participate fully in later in social life. In the twenty-first century, literacy and numeracy skills underpin workforce participation, productivity and economy of the country, at large. Research studies indicate that people with advanced language, literacy and numeracy skills are more likely to be employed and participate in community life. Such individuals are, hence, more informed, which means they are likely to experience better health and have positive social outcomes. They are also more inclined to engage in further training. Further, improved literacy and numeracy skills have a generational flow effect with researches indicating that parents transfer these skills to their children. These skills are transferred at a stage when a child starts building a foundation that would be necessary for learning in years to come. Without this base, it is possible but difficult to help children catch up to where they need to be (Fuson, 2004).

Several researchers have studied the extent to which children's achievements around the time of starting schooling can predict their achievements in reading or mathematics several years later (Jordan, Kaplan, Ramineni and Locuniak, 2009). From such studies, it appears that the extent of a child's knowledge and learning around the time of starting school or in the first year of school is a strong indicator of one's levels of achievement in the next few years. Such studies underline that learning of basic literacy and mathematics in preschool and first year of school is important. Thus, early mathematics skills are found to be the strongest predictor of later success in mathematics and reading (Duncan, et al., 2007).

Trends in Early Number Instruction

Since the mid–1990s, there have been significant developments in approaches to instruction in the concept of number and early arithmetic. These include better ways to assess children's early 'number knowledge' and teaching of topics at advanced levels. Several studies in the 1990s provided a basis for profound change to the focus and scope of assessment and instruction in number and early arithmetic (Wright, 1996). These studies highlighted key factors, such as diverse backgrounds of school entrants and their knowledge of early arithmetic. Also, the notion that pre–number topics constitute essential prerequisites for learning early number was increasingly under challenge (Hiebert, Carpenter and Moser, 1982).

With formal schooling, children begin to develop a new understanding of numbers, the association of numbers with sets of objects, meaning of symbols like '='and that 8 is 'more' than 5. They begin to develop the use of a mental number line and association of symbols, such as 8 and 5 on the number line (Carpenter, Franke, and Levi, 2003). These are essential precursors to deepen the mathematical knowledge. Children also begin to develop a better understanding of conservation of numbers with the establishment of one–to–one correspondence between two sets of items and their representing numbers, in what Gelman and Gallistel (1986) refer to as the 'how to count' principles of counting. These principles consist of each object or item within a group of objects or array of items associated with only one number name, and the understanding that the final number of objects or items in a grouping is representative of the overall group.

Early Assessment and Intervention — Implications

Direct assessment of early numeracy skills is important in case of young children, given their strong association with later mathematical achievement. Assessment of early mathematics skills must include measures of numerical symbol knowledge, such as number identification based on numerals and arrays, and counting, emphasising cardinality and ordinality (Merkley and Ansari, 2016). Given the findings of developmental continuity in preschool non-symbolic arithmetic and later symbolic arithmetic, manipulation of non-symbolic numbers should also be part of early mathematical assessment. Non-symbolic number skills and representations refer to ways of representing numbers without using symbols, and typically, involve numerical manipulations or transformations on objects, as well as, comparisons of the magnitude of sets of objects. For example, young children can perform simple addition and subtraction with non-symbolic numerical representations, e.g., with actual objects or pictures of objects. Such early numeracy skills are assessed separately in research based studies but are not currently available as separate normative based tests. However, there are some standardised measures of mathematics like Test of Early Mathematics Ability – Third Edition that are suitable for preschool children. One advantage of the Test of Early Mathematics Ability – Third Edition is that it was created on the basis of theory and empirical studies of mathematical development. It contains items that tap early numeracy skills that correspond with the sequence in which such skills are typically acquired. It is suitable for assessing numeracy very early — from 36 months and it explicitly measures the early numeracy skills shown to be important for later mathematics, such as counting (ordinal and cardinal knowledge), number identification, non-symbolic arithmetic, and understanding of rudimentary mathematical terms, such as 'more' (Ginsburg and Baroody, 2003).

It seems relevant to assess early mathematical skills of children at the beginning of formal mathematical learning (in other words, mathematical school readiness). This allows one to identify children with low mathematical skills at the beginning of Class I and employ appropriate educational support measures, such as paying individual attention and giving selected worksheets to them. These support measures will provide an ideal basis for later mathematical learning and help eliminate numerical shortcomings. However, in order to identify children in difficulty, teachers need validated and standardised tools. Many share that they have to rely on their own 'home-made' tools or intuition, which is not ideal and makes them feel uncomfortable. Data showing that teachers' judgments are perceptually biased and that they face difficulty in judging their students' cognitive potential confirm the actual problem of the situation (Fischbach, et. al., 2013).

However, with continued practice, there is a growth in familiarity with numbers and their values, building the learners' confidence. This can include advancing to new strategies, such as counting from the larger addend (min strategy) when they are shown two numbers representing two groups of objects that are being added together (Siegler and Shrager, 1984). An example of an earlier 'sum strategy' or the 'counting-all method' (Fuson, 2004) is when a child is asked to solve '5 + 4'. The child counts and shows five fingers on one hand representing '5' and counts and shows four fingers on the other hand representing '4', and then, counts all the fingers — 1, 2, 3, 4, 5, 6, 7, 8, 9. In time, the child may progress to just put one's fingers up, already knowing that one hand represents '5' and then count '6, 7, 8, 9' to add '4' to '5'. Therefore, as the child progresses with one's counting skills and is asked to solve a problem like '5 + 4', one may count applying the min strategy by counting from the larger addend (5) to get the answer.

With practice, the children begin to store information. Initially, they may retrieve the answer to a mathematical problem but may lack confidence. They may retrieve the answer and then verify it by using a counting strategy (Siegler and Schrager, 1984). With practice, they gain confidence and process information faster in solving mathematical problems. They may also build confidence in the use of fact retrieval for solving simpler mathematical problems, such as retrieving knowledge for numbers of equal value, such as '2 + 2 = 4' (Ashcraft, 1982; Hamann and Ashcraft, 1986; Siegler and Shrager, 1984). But that there is a level of 'automatisation' of the knowledge that '2 + 2 = 4' is preceded by a conceptual stage that requires counting. At the same time, becoming efficient at mathematics requires automatisation of the subsequent stage, rather than constant recursion to the earlier stages. For more difficult mathematical problems, this "extended practice" provides the skills and proficiency required for rapid and accurate processing, freeing up cognitive resources so that children are able to pay attention to more elements of the task at once (Pellegrino and Goldman, 1987). Therefore, children, who demonstrate difficulty with single-digit numbers like '5 + 6', will find advanced mathematics more challenging (Gersten, Jordan and Flojo, 2005). In other words, recursion to more primitive strategies, though it does show an understanding of the concept, might impede further conceptual understanding and progression if operational automaticity is not achieved.

As children continue to develop their understanding and become more proficient with skills, such as single-digit addition and subtraction, they move to double-digit addition and subtraction problems and learn place value. They also begin to apply more advanced strategies with the use of tens and ones. An example of this is the calculation of '48 + 31', which requires breaking down each number into its specific tens and ones like 40 + 30 = 70 and 8 + 1 = 9. Therefore, the answer is 79 (Clements, 2004). With continued practice and integration of these skills into simple word problems, children are able to work with greater computations and develop problem solving competence (Fuson, 2003). The understanding of computation and integration of methods, and practice with both, leads to "computational fluency" (Fuson, 2003). Yet, to get to this point, the children must know how to count. They must understand how to simultaneously count, keep a track of objects, continue with this progression and develop automaticity as the foundation of success with basic number operations like addition, subtraction, multiplication and division.

Formative Assessment helps Targeted Teaching

In order to implement targeted teaching, teachers need accurate information about what students know and what they are ready to learn. They can acquire this information is through the use of formative assessment, which has shown significant effect on learning across the spectrum.

Formative assessment may employ a number of methods to monitor student learning, and identify concepts and skills that they may find difficult to grasp. It may also include mathematical problems set at a slightly challenging level in order to help them reach their potential. In other words, it is a method of assessment for learning (Black and Dylan, 1998). Some of the key elements of formative assessment include the following.

- Identification of goals, outcomes and criteria for achievement
- Based on the teacher's feedback, a student realises the level of one's current knowledge and becomes actively involved in future directions of one's learning.
- Teachers responding to feedback by modifying teaching strategies (Karpinski and D'Agostino, 2013).

Conclusion

A detailed knowledge of children's early abilities allows optimal adaptation of learning and instruction to their individual needs. It is, therefore, critical to accurately and efficiently assess a school entrant's abilities in the core domains of schooling, such as mathematics. Quality professional learning improves teaching quality. High-quality teaching is the greatest influence on students' engagement and outcomes in school (Hattie and Yates, 2014). Focus on teachers' professional learning improves the teaching of literacy and numeracy skills. Thus, it is important for schools and educational jurisdictions to find ways to significantly advance teachers' pedagogical knowledge in the area.

To ensure that children effectively develop a wide range of competencies that form the foundations of early mathematics, it is necessary to adequately measure their progress in all aspects of early mathematics. Teachers can, generally, distinguish high performing learners just by observing. However, they would require strong assessment tools to make finer differentiation, particularly, at the individual skill or concept level. Efficient and reliable assessment tools can serve a twofold purpose. Firstly, they can be used to identify children who need additional instruction. Secondly, they can be used to identify the specific aspect(s) of mathematical knowledge, in which a student needs further instruction.

REFERENCES

Ashcraft, M. 1982. 'The development of mental arithmetic: A chronometric approach'. *Developmental Review*. Vol. 2. No. 3, pp. 213–236.

Black, Paul and *Wiliam* Dylan. *1998*. 'Assessment and Classroom Learning'. *Assessment in Education*. Taylor & Francis. London. UK. Vol. 5. No. 1.

Clements, D. H.2004. Conference Working Group. In D. H. Clements, J. Sarama and A. M. DiBiase (Eds.). *Part One: Major Themes and Recommendations*. Lawrence Erlbaum Associates. Mahwah. New Jersey, pp. 1–72.

Duncan, G. J., et al. 2007. 'School Readiness and Later Achievement'. *Dev. Psychol.* Vol. 43, pp. 1428–1446.

Fischbach, A., et. al. 2013. 'Do teacher judgments of student intelligence predict life outcomes?' *Learning and Individual Differences*. Vol. 27, pp. 109–119.

Fuson, K. C. 2003. 'Developing mathematical power in whole number operations'. In J. Kilpatrick, W. Martin and D. Shifter (Eds.). *A Research Companion to Principles and Standards for School Mathematics*. Reston, VA: National Council of Teachers of Mathematics, pp. 68–94.

———. 2004. 'Pre–K to Grade 2 Goals and Standards: Achieving 21st century Mastery for All'. In D. H. Clements (Ed.). *Engaging Young Children in Mathematics: Standards for Early Childhood Mathematics Education.* Lawrence Erlbaum Associates, Inc. New Jersey. UK, pp. 105–148.

Gelman, R. and C. R. Gallistel. 1986. *The Child's Understanding of Number.* Harvard University Press. American Psychological Association.Washington, D.C. USA.

Gersten R, N. C. Jordan and J. R. Flojo. 2005. Early identification and interventions for students with mathematics difficulties. *Journal of Learning Disabilities*. Vol. 38. No. 4, pp. 293–304.

Ginsburg, Herbert P. and Arthur J. Baroody. 2003. *The Test of Early Mathematics Ability – Third Edition* (TEMA–3).

Hamann, M. S. and M. H. Ashcraft.1986. Textbook presentations of the basic addition facts. *Cognition and Instruction.* Vol. 3, pp. 173–192.

Hattie, J. and G. Yates. 2014.*Visible Learning and the Science of How We Learn.* Routledge. New York. USA.

Hiebert, J., T. P. Carpenter and J. M. Moser. 1982. 'Cognitive development and children's solutions to verbal arithmetic problems'. *Journal for Research in Mathematics Education.*Vol. 13, pp. 83–98.

Jordan, N. C., D. Kaplan, C.Rameneniand M. N. Locuniak. 2009. 'Early math matters: kindergarten number competence and later mathematics outcomes'. *Developmental Psychology*. Vol. 45, pp. 850–867.

Karpinski, A. C. and J. V. D'Agostino. 2013. 'The role of formative assessment in student achievement'. In J. Hattie and E. M. Anderman (Eds.). *International Guide to Student Achievement.* Routledge. New York, pp. 202–204.

Merkley, R., and D. Ansari. 2016. Why numerical symbols count in the development of mathematical skills: Evidence from brain and behavior. *Current Opinion in Behavioral Sciences. Vol. 10,* pp. 14–20. https://doi.org/10.1016/j.cobeha.2016.04.006.

Pellegrino, J. W. and S. R. Goldman.1987. Information processing and elementary mathematics. *Journal of Learning Disabilities. Vol. 20.* No. 1, pp. 23–32, 57. https://doi.org/10.1177/002221948702000105.

Siegler, R. S. and J. Shrager. 1984. 'Strategy choices in addition and subtraction: How do children know what to do?' In Catherine Sophian (Ed.). *Origins of Cognitive Skills: The Eighteenth Annual Carnegie Symposium on Cognition.* Lawence Erlbaum Associates Publishers, London. UK.

Carpenter, Thomas P., Megan Loef Franke and Linda Levi. 2003. *Thinking Mathematically: Integrating Arithmetic and Algebra in Elementary School.* Pearson Education. Canada.

Wright, R. J. 1996. Problem-centred mathematics in the first year of school. In J. Mulligan and M. Mitchel more (Eds.). *Children's number learning: A research monograph of MERGA/AAMT.* Australian Association of Mathematics Teachers. Adelaide, Australia, pp. 35–54.