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Mapping and predicting literacy and reasoning skills from early to later primary school

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ABSTRACT

This study explored the relations between early indicators of literacy, numeracy and reasoning with later school performance in these abilities. In pursuit of this aim, appropriate tests were administered to 1073 children at the start of school in England who were divided into four age groups (mean ages of groups: 4.12, 4.37, 4.62, and 4.88 years old) and again during their third year of primary school when they were six to seven years of age. Analysis of variance revealed large improvement in all abilities throughout the fifth year of life. Girls outperformed boys only in language but differences diminished extensively at the end of this year. Structural equation modeling showed that all three abilities of language, mathematics and reasoning emerge as distinct factors strongly related to a general ability factor (g) at both testing waves. General ability at the start of school highly predicted G in the third year of primary school at age 6–7 years. The reading ability of children in the second half of the fifth year was also directly related to g at age 6–7, especially for girls. Implications for developmental theory and education are discussed.

All cognitive functions change extensively in early and middle childhood. From the second year of life onwards, language, mathematical, and reasoning abilities expand and are practiced extensively. From 3 to 5 years children become aware of various aspects of language, including the function of words as representations of objects, actions, and concepts, the phonological organization of sounds in words, and relations between word sounds and writing or pictures (Otto, 2013). In mathematics, children acquire basic arithmetic skills, including the ability to discriminate numerically between sets of objects, operate on small numbers, represent relations between numbers, make judgements about numerical magnitudes, and organize their knowledge in reference to a mental number line (Dehaene, 2011). Also, children at this age demonstrate general inferential and problem solving skills, drawing inductive inferences on the basis of similarities between objects and concepts (Carey, 2009).

At this period of life children often enter formal education. In many countries preschool education starts at 4–5 years and primary school starts at 5–7 years of age (statutorily at 5 in the UK but between age 4 and 5, in practice). Preschool education should emphasize the construction of basic social and cognitive skills that would enable children to adjust to the complex social and symbolic environment of society and prepare them to acquire the reading, arithmetic, and problem solving skills taught in primary school. To be successful, education needs accurate diagnostic tools which specify children's capabilities in each of the processes mentioned above. The present study was conducted to partly help validate and evaluate one such assessment, the PIPS (Performance Indicators in Primary Schools), on entry to preschool (Tymms, 1999, Merrell & Tymms, 2001). The PIPS baseline was designed to specify the developmental level of children's abilities at the age of 4 to 5 years. In this study we explore the relationships between three abilities (i.e., language, mathematics, and reasoning) and their predictive power two years later, when children are in their third year of primary school in England (known as Year 2, when children are aged 6–7 years). It is noted that PIPS assesses aspects of reading and numeracy that are addressed by many other similar tests (e.g., Cartwright, 2002; van de Rijt et al., 2003). In addition, it involves tests intended to examine abstract reasoning processes. Thus, it can be used to specify both readiness for school-specific processes and also the possible involvement of more general processes that may influence school-related processes.

From an educational perspective, the term "school readiness" refers to the extent to which children have developed skills and abilities that will enable them to succeed in their learning at school (UNICEF, 2012); they are at the stage when they will hopefully learn to read and do simple arithmetic if they are given instruction. It has been the subject of much investigation. For example Duncan et al. (2007) showed that early measures of math, reading, and attention were the best predictors of later academic success. Pre-school interventions are often judged initially by their impact on school readiness and some programs

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have had great success (Ramey & Ramey, 1998). The measurement of school readiness often comes under the heading baseline assessment and a recent publication from UNESCO (2016) gives a flavour of the challenges involved in developing baseline assessments for educational purposes. We hope that this study will provide a refined picture of how mental processes on entrance to school relate to school learning a few years later.

There is a consensus in educational and developmental research literature that these abilities are inter-related and changes in each of them is systematic. There is research showing that early literacy skills, such as letter knowledge, phonological sensitivity, and oral sensitivity are highly stable from 3.5 to 5.5 years (Chistopher, Stephen, & Jason, 2000). Also, counting and relational skills before formal schooling predict the acquisition of basic arithmetical skills and overall mathematical performance in early primary school (Aunio & Niemivirita, 2010). Also, some literacy skills (i.e., print knowledge and vocabulary) but not others (phonological awareness) predict numeracy skills (i.e., numbering, numerical relations, and arithmetic operations) in the 3–5 years period (Purpura, Hume, Sims, & Lonigan, 2011). Evidence about the relations of these skills with broader measures of intelligence is less consistent. On the one hand, there is evidence that general intelligence (Stanovich, Cunningham, & Feeman, 1984) or domain-general abilities such as executive control (Cartwright, 2012) underlie these relations throughout preschool and primary school. On the other hand, some studies found that non-verbal IQ in early preschool does not relate to later reading skills (Cartwright, 2002).

1. Towards an integrated differential-developmental model of learners

To make sense of these findings a comprehensive model is needed that can do justice to both factors underlying individual differences in mental processes and their development with age. Unfortunately, psychometric theories of individual differences of mental abilities underestimate development and developmental theories underestimate factors of individual differences (Demetriou & Spanoudis, in press). The present study was designed in the context of an integrative model that draws on psychometric and developmental theory.

Specifically, in psychometric theory of individual differences a hierarchical three-level model of the organization of mental abilities is commonly accepted (Carroll, 1993; Deary, 2000; Hunt, 2011). According to this model, individual differences in mental functioning may emerge from any of three independent levels in the organization of mental processes. The first level involves many specific skills, including various reading skills, various mathematical skills, various reasoning skills, etc. These skills are organized into broad abilities at the second level, such as verbal ability, mathematical ability, reasoning ability, etc. For instance, facility in dealing with words, executing arithmetic operations, capturing underlying relations, respectively, may underlie children's ability to learn language, mathematics, or master reasoning processes. These in turn are constrained by very general processes at the first level, such as processing efficiency and inferential power. This is general intelligence or g that is closely reflected in measures of intelligence, such as the IQ, captured by various intelligence tests. For instance, children who are able to keep in mind large amounts of information are more likely than children who are weak in this regard to combine words and decipher their meaning or master the complexities imposed by the abstract nature of mathematical relations. Each higher level is a more powerful source of individual differences because it sets the frame for an increasingly broad set of processes.

However, this model is silent about development, underestimating the role and importance of different mental processes at different phases of development. Demetriou et al. (2013, 2014a,b) proposed a developmental model specifying how abilities associated at each of the three hierarchical levels above are expressed and related in development from birth through early adulthood. According to this model, g involves three inter-dependent processes: (i) Abstraction; (ii) representational Alignment; and (iii) Cognizance (hereafter referred to as the AACog mechanism. Abstraction spots or induces similarities between patterns of information, using mechanisms that may vary in development. Alignment is a relational mechanism that maps representations onto each other, enabling comparisons driven by current understanding or learning goals (Demetriou et al., 2013). Cognizance is awareness of the objects of cognition (e.g., "I know that I see a cat), cognitive processes (e.g., "I know that I can think of the cat running), allowing executive control and mental planning.

It is beyond the scope of the present paper to discuss the relations between this model and psychometric theory of intelligence (see Demetriou et al., 2014a,b) but it is noted here that AACog is only partly related to psychometric g. Like g, it involves abstraction and relational processes allowing search and encoding of similarities or regularities in the environment into representations and concepts. Unlike g, it is minimally inferential and minimally representational. That is, it cannot be identified with any specific type of reasoning, such as inductive and analogical reasoning, or specific aspects of representational efficiency, such as short-term or working memory. Reasoning and problem solving processes in all domains must be constructed as such and representational efficiency processes reflect rather than cause changes in the nature of representations with growth (Demetriou et al., 2013, 2014a,b).

Specifically, it is assumed that this mental core develops in four cycles, with two phases in each. Moving across cycles is associated with the emergence of new forms of representation; changes within cycles are associated with increasing awareness of them and skill in using them. In succession, the four cycles operate with episodic representations from birth to 2 years (remembrances of actions and experiences preserving their spatial and time properties), realistic mental representations from 2 to 6 years (blueprints of episodic representations where spatial and time properties are reduced, associated with symbols, such as words), generic rules organizing representations into conceptual systems from 6 to 11 years, (e.g., concepts about categories of things, exploring causal relations) and overarching principles integrating rules into systems where truth and multiple relations can be evaluated from 11 to 18 years (i.e., principles specifying how rules may be integrated). Changes within cycles occur at 4 years, 8 years, and 14 years, when representations become explicitly cognized so that their relations can be worked out, gradually resulting into representations of the next cycle (Demetriou et al., 2014a).

Here we focus on the two cycles related to the present study. The first cycle of mental representations lasts from 2 to 6 years. In the first phase of this cycle, from 2 to 4 years, action-based episodic representations of the previous cycle are elevated into symbol-based mental representations. In this early phase, representations have a transparent relation to objects or events and they function as undifferentiated ensembles. Specifically, children use language efficiently in their interactions but they do not yet demonstrate awareness of phonological, grammatical or syntactic characteristics of speech nor do they handle components independently of each other. In mathematics, there are "proto-quantitative schemes" (e.g., "few", "many", "a lot") which are used as representational blocks that may generate mathematical judgements triggered by perceptual appearances. At this phase they can recognize the effect of adding and taking away elements from an aggregation of objects if they lie within the subitization limit (3–4 objects) but they do not yet possess the notions of numerical operations as such. In reasoning, inductive inferences are based on perceptual similarity that enables children to associate objects with categories on the basis of a commonly shared attribute. Language learning draws heavily on this process. For instance, associating an object with a novel name (i.e., "this is a dax" or "this is a diffle") leads 3-years-old children to infer that other objects of the same shape are "dax" or "diffle" (Becker & Ward, 1991; Landau, Smith, & Jones, 1988). Deductive inference as such does not exist at this phase but representations may be co-