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Augmenting intelligence: Developmental limits to learning-based cognitive change

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ABSTRACT

We investigated if learning relational reasoning in mathematics generalizes to other domains and general intelligence, including speed, attention control, and working memory. A total of 118 10-year olds were involved, allocated to an experimental and a control group. The experimental group was involved in 12 learning sessions addressed to various aspects of relational reasoning. Various analyses, including Rasch scaling, growth modeling and structured means analysis, showed significant but not sustainable learning gains in the ability trained. However, learning transferred to similar processes in analogical reasoning and also to attention control and working memory, indicating sustainable effects on mechanisms underlying general intelligence. An upper developmental constraint to learning was found. Implications for psychometric and developmental theories of intelligence and for education are discussed.

Learning is of central concern to many disciplines. In the psychology of intelligence, researchers focus on a double face problem. On the one hand, they try to specify how learning is constrained by general intellectual ability (i.e., g or its measured manifestation, IQ). On the other hand, they examine how learning may change general intellectual ability itself, if at all (Hunt, 2011; Jensen, 1998). In developmental psychology, this problem is restated in terms of developmental constraints. That is, it is examined, on the one hand, if learning possibilities vary as a function of developmental level (or stage) of cognitive processes (Brainerd, 1977; Piaget, 1964). On the other hand, it is also examined if learning may accelerate transition across developmental levels and elevate individuals higher on a developmental hierarchy than it would be possible by spontaneous development (Brainerd, 1977; Efklides, Demetriou, & Gustafsson, 1991; Klauer, 1998, 2014; Klauer & Phye, 1994). In educational science concerns are more practical, focusing on the stability of learning gains and their transfer to other domains (Csapó, 1999; Greiff et al., 2014; Klauer & Phye, 2008). This study is related to all of these concerns: We examine if learning to use general cognitive processes (e.g., classification and induction of relations) in a specific domain (i.e., mathematics) (i) augments general intelligence (defined as a latent construct underlying several domains in addition to mathematics), (ii) transfers to domain-free representational and processing capacities, such as processing speed, attention control, and working memory, (iii) varies over time, and (iv) is constrained by developmental level.

There is general agreement that g (or IQ, as a global measurement of g) is systematically related to learning. On the one hand, high g implies faster, deeper, and more stable learning than low g (Jensen, 1998). On the other hand, learning (school-based or experimentally induced) influences intelligence positively. There is evidence that each extra year of schooling augments IQ by 2–4 IQ units (Ceci, 1991; Gustafsson, 2008; Gustafsson & Undheim, 1996). However, it is disputed if this effect reflects a better handling of the test itself or a real increase in intelligence. Jensen (1998) suggested that these effects are shallow, primarily reflecting improvement in test taking skills rather that a change in g itself. There is empirical support for this view. For instance, te Nijenhuis, van Viane, and van der Flier (2007) claimed that test–retest gains and gains related to systematic learning experiences addressed to the abilities related to various intelligence tests are not related to g. It is also claimed that gains in IQ from long-term programs, such as the Head Start program, did not relate to g because they do not affect the underlying processing and inferential mechanisms of g (te Nijenhuis, Jongeneel-Grimen, & Kirkegaard, 2014).

The assumption that g is impervious to learning was invoked to explain the finding that increases in IQ because of learning fade out with time. However, this interpretation ignores the possible developmental variation of g. That is, developmental theory assumes that development transforms the underlying g construct in both its representational and

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inferential efficiency. Therefore, when intervention is delivered only at a given time T but measurements are taken at both time T and a relatively remote time T + 1, what appears to be a fade out effect because performance at T + 1 is lower than performance at T simply reflects the fact that g at T + 1 is not identical to g that was affected by the learning experience. This possibility renders conclusions regarding the depth of learning effects (test taking expertise or underlying g-loaded mental processes) unfounded. A critical test of this assumption would be to examine if g-related learning generalizes to underlying processing and representational mechanisms, such as attention control and working memory.

Developmental research is only partially in agreement with psychometric research. On the one hand, somehow echoing Jensen's position about g-bound constraints of learning, Piaget (1964) (see also Inhelder, Sinclair, & Bovet, 1974) himself postulated that learning is constrained by the current mental structure. That is, inferential patterns and concepts exceeding the assimilatory possibilities of the current structure cannot be learned, because this structure would reject or distort patterns and concepts that cannot be meaningfully understood. On the other hand, Piaget did accept that learning directed to the integration and consolidation of the mental operations underlying the current mental structure may both accelerate the development of this structure and generalize to concepts drawing upon it. In psychometric terms, this would be equivalent to change in mental age as a result of learning.

Research in this tradition investigated the effects of learning on all sorts of Piagetian structures and concepts (Brainerd, 1977; Efklides et al., 1991; Inhelder et al., 1974; Shayer & Adey, 2002; Strauss, 1972). In line with Piaget, this research found that learning focusing on the integration of mental operations was more successful, stable, and transferrable than learning focusing on the acquisition of specific skills and processes. Also, it was found that progress within a stage is much easier to attain than progress across stages. Along these lines, Klauer and his colleagues (Klauer and Phye, 1994; Klauer, Willmes, and Phye, 2002) developed a program that trained children to reason inductively, drawing from both the developmental and the psychometric approach. This program adopted the Piagetian assumption that processing of similarities and differences between objects or representations, inducing their underlying relations, and integrating them into classificatory or relational schemes is crucial for operational development (Inhelder et al., 1974). Notably, this assumption coincides with the psychometric assumption that induction of relations between objects or representations and of relations between relations is the substance of g (Carroll, 1993; Spearman, 1904) or fluid intelligence (Cattell, 1963). Klauer and colleagues maintained that their program permanently increased fluid intelligence and improved academic performance (Klauer, 1998, 2014; Klauer & Phye, 2008; Klauer et al., 2002).

A stricter test of the effects of learning would be to specify if an intervention transfers to fundamental representational and processing capacities underlying the ability trained, such as attention control or working memory. This is because individual differences in fluid intelligence are assumed to reflect differences in these fundamental processes. Specifically, fast processing, (Jensen, 1998), attention control (Diamond, 2013), and working memory (Kyllonen and Christal, 1990) are associated with higher intelligence. In developmental research, changes in each of these processes were associated with changes in thought and problem solving (Case, 1985; Demetriou, Christou, Spanoudis, and Platsidou, 2002; Kail, 1991, 2007; Pascual-Leone, 1970; Pascual-Leone and Johnson, 2011). It was suggested that these processes relate in a cascade fashion such that increasing speed facilitates attention control, which facilitates working memory, which facilitates transition to higher levels of reasoning and problem solving (Fry and Hale, 1996, 2000; Kail, 2007).

There is research examining if modifying these processes transfers to g. Findings so far are inconclusive. Several studies showed that training executive processes in working memory, such as information binding and attention control, did transfer to fluid intelligence (Jaeggi, Buschkuehl, Jonides, and Perrig, 2008) and every day and school performance (Barnett, 2011; Diamond, 2013). However, extensive evaluation of this literature suggested that training executive processes confounds changes in the command of these processes per se with changes in inferential processes shared by working memory and Gf (Melby-Lervag & Hulme, 2013; Shipstead, Redic, & Engle, 2012). That is, what is supposed to be transfer of learning effects from WM to Gf it is actually learning directly affecting Gf. Along the same line Nutley et al. (2011) showed that training nonverbal Gf related reasoning processes did raise Gf in 4 years old children; however, training working memory processes, although effective to improve working memory performance, did not transfer to Gf. On the contrary, Rueda, Checa, and Combita (2012) found that training attention control did transfer to Gf in 5 years old children.

Incongruence between studies may be apparent rather than real. That is, it might be the case that the possible impact of learning varies with age, because the role of different processes varies with development. In this case, differences between studies may simply reflect differences in the processes addressed vis-à-vis participants' age. Demetriou and colleagues (Demetriou et al., 2013; Demetriou, Spanoudis, & Shayer, 2014; Demetriou et al., 2014) advanced a model of intellectual development postulating that these relations vary systematically with developmental phase. According to this model, fluid intelligence develops through four major reconceptualization cycles (the ReConceP sequence), with two phases in each. In succession, the four cycles operate with episodic representations (birth to 2 years), realistic mental representations (2–6 years), rule-based reasoning integrating mental representations (6–11 years), and principle-based reasoning integrating rules (11–18 years). Transitions within cycles occur at 4 years, 8 years, and 14 years, when relations between the representational units of the present cycle are metarepresented into the representational units of the next cycle (Christoforides, Spanoudis, & Demetriou, in press). These cycles were specified on the basis of performance on a large variety of tasks addressed to reasoning and problem solving in various domains. Many of these tasks were used here to test the reasoning in various domains (see Method). These include pragmatic and conditional reasoning, categorical and analogical reasoning expressed through verbal, numerical, and figural content, scientific reasoning addressed to various aspects of hypothesis formation and testing, and various aspects of spatial reasoning, such as mental rotation and orientation in space (Demetriou & Kyriakides, 2006).

Demetriou et al. (2013, 2014) showed that changes in Gf in the first phase of each cycle (i.e., at 6–8 years and 11–13 years) are related to changes in processing efficiency. Measures of processing speed, such as choice reaction times and Stroop-like tasks of attention control were used to measure processing efficiency. Changes in the second phase of each cycle (i.e., 4–6 years, 8–10 years, and 13–16 years) are related to changes in working memory. Tasks addressed to various aspects of short-term memory and executive processes in working memory were used (Demetriou et al., 2002; Demetriou, Mouyi, & Spanoudis, 2008; Demetriou et al., 2013; Demetriou et al., 2014). They suggested that this pattern reflects differences in the processing requirements of developmental acquisitions. At the beginning of cycles processing speed is a better index because it reflects changes in the facility of using the new mental units. Later in the cycle, when networks of relations between representations are established, working memory is a better index because alignment and inter-linking of representations both requires and facilitates working memory.

In short, this model posits that intelligence is a universe of processes which give meaning to the world, handling change sensibly and adaptively. The main meaning-making processes are abstracting, aligning and relating, and filling in gaps of information and evaluating them by inference and reasoning. It is a developmental process that accomplishes these aims under the representational and processing constraints of the current phase, finding ways to minimize the constraints and enhance possibilities. In so doing it causes development in