Domain Specific and Domain General Mechanisms Underlying Arithmetic Knowledge and Two Profiles of Dyscalculia

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Abstract

The present research extends the active debate surrounding the factors that contribute to arithmetic knowledge on the one hand and the development of dyscalculia on the other. Some claim that domain-specific numerical cognition, such as the ability to compare quantities and numbers, contributes to the development of arithmetic knowledge. Others attribute it to domain-general cognition, such as working memory and executive functions. While most research in the field has examined **either** the contribution of numerical cognition **or** that of general cognition to achievements in arithmetic knowledge, only a few researchers have examined the contribution of **both together**. Furthermore, arithmetic knowledge has usually been examined as a single entity, without distinguishing between the three kinds of arithmetic knowledge: factual knowledge, procedural fluency, and conceptual understanding.

The object of the present research is to investigate the contribution of numerical and general cognition to achievements in each of these three kinds of arithmetic knowledge among students of normal development (experiment 1) and two profiles of dyscalculia (experiment 2) at the beginning of junior high school.

Until today only two research projects have investigated whether numerical or general cognition makes a relatively **greater** contribution to **each** kind of arithmetic skill for students with normal development. These projects investigated students in first grade (Fuchs et al., 2010) and fourth to sixth grade (Träff, 2013). They concluded that for the more basic skills in the hierarchy of arithmetic knowledge (factual knowledge) the contribution of numeric cognition was greater, and for the more advanced skills (conceptual understanding) the

contribution of general cognition was greater. At the same time, the suggestion was made that as the age of the subjects increases the complexity of arithmetic knowledge increases, and this causes the contribution of general cognition to be relatively larger (Träff, 2013). The present research extends the canvas of developmental progress and examines an older group – seventh grade students. Furthermore, in addition to the metrics of general cognition used in previous projects, our research also investigated executive functions: updating, shifting, and inhibition (Miyake et al. 2000), since it has been shown that these executive functions contribute to arithmetic knowledge. Also, the individual contribution of them **to each** kind of arithmetic knowledge has not previously been examined separately (Cragg & Gilmore, 2014) and ours is the first research to do so.

Side-by-side with the population of students with normal development is a population suffering from dyscalculia – learning disabilities in the acquisition of arithmetic proficiency. There is as yet no accepted definition of the phenomenon and no consensus as to its causes. Some maintain that dyscalculia is a homogeneous phenomenon derived from numerical core deficit with its origin in the intra-parietal sulcus (IPS) of the brain. This deficit damages the ability to estimate quantities by the approximate number system (ANS). Others claim that it is a heterogeneous phenomenon deriving from a range of deficiencies in numerical and/or general cognition. In order to assess the causes of dyscalculia, precise criteria for the test population must be set to distinguish between different profiles of disability, following which the cognitive factors underlying each profile must be examined (Price & Ansari, 2013b). In much research the criterion for sampling subjects with dyscalculia has been significant difficulty in factual knowledge, since this is the most obvious and common expression of the phenomenon. However, there are two distinct groups among those with significant difficulties with factual knowledge: those with difficulties with factual knowledge and also with other

types of arithmetic knowledge (General Dyscalculia - GD) and those who only have difficulties with factual knowledge and whose achievements in other types of arithmetic knowledge are normal (Specific Dyscalculia - SD) (Kaufmann et al. 2013).

As far as we are aware, only one research project to date has made a comparison between subjects with GD and SD (Skagerlund & Träff, 2014). There the two groups were selected from remedial arithmetic classes, and as a result their proficiency was lower than those of students of normal development. In other words, the group with SD also had lower than normal achievements. Our research sharpens the distinction between the two groups. GD was defined as difficulty with the three types of arithmetic knowledge and SD was defined as difficulty with factual knowledge (like those with GD) **but normal achievements in other types of arithmetic knowledge**. In addition, in the earlier research (Skagerlund & Träff, 2014), subjects with GD and SD were only compared according to numerical cognition metrics. In our research comparison was also made according to general cognition metrics. Furthermore, our research investigated for the first time the connections between each of the types of arithmetic knowledge and each of the cognitive metrics – numerical and general – among subjects with GD and SD.

In experiment 1, 103 seventh grade students were selected, with normal achievements in arithmetic, and normal non-verbal reasoning and reading fluency. The research question dealt with the relative additional contribution of numerical cognition (over and above general cognition) and general cognition (over and above numerical cognition) to achievements **in each** of the three types of arithmetic knowledge for students with normal development. It also examined the individual contribution of (numerical and general) cognition metrics to each

type of arithmetic knowledge. These questions were examined a second time controlling for arithmetic knowledge lower in the hierarchy.

Experiment 2 included 55 seventh grade students with normal non-verbal reasoning and reading fluency. The participants were divided into three groups. The first group included 19 subjects with GD (34.5%); the second group included 17 subjects with SD (30.9%); and the third group, the control group, included 19 subjects with normal development (34.5%). The research question made a comparison between (numerical and general) cognition metrics for two profiles – GD and SD. It also examined the correlations between numerical and general cognition metrics for the three types of arithmetic knowledge in both defined profiles.

Principal results of the research:

Experiment 1 – Seventh grade students with normal development

1. General cognition makes a relatively larger contribution than that of numerical cognition to each of the three types of arithmetic knowledge, while numerical cognition does not make a relatively larger contribution than general cognition.
2. Phonological working memory and naming speed make an individual contribution to factual knowledge, and executive functions of shifting and updating make an individual contribution to procedural fluency and conceptual understanding respectively, after controlling for arithmetic knowledge lower in hierarchy.

The results of the research demonstrated the importance of the distinction between the three types of arithmetic knowledge, as expressed both in their hierarchical relationship and in the different underlying cognitive factors. Furthermore, our research shows that at the beginning of junior high the added contribution of numerical cognition to arithmetic knowledge beyond that of general cognition is negligible.

Experiment 2 – Seventh grade students with GD and SD:

1. Students in both groups have difficulties with numerical cognition metrics (subitizing, counting and symbolic comparison tasks) and general cognition metrics (phonological working memory and naming speed). However, while subjects with GD also had difficulty with executive functions (shifting and updating), those with SD had normal executive functions.
2. Although subjects with GD and SD had an equally low level of factual knowledge, the correlations between factual knowledge and other cognitive metrics differed between the two groups. In the GD group factual knowledge correlated with visual working memory and executive functions of shifting and updating (as is characteristic of young children beginning to acquire such knowledge), and in the SD group factual knowledge correlated only with naming speed.

These results are consistent with the heterogeneous approach which attributes the source of dyscalculia to both numerical and general cognition, and not to a single factor in the approximate number system (ANS). Furthermore, our research stresses the importance of executive functions which distinguish between the two profiles and allow students with SD to continue their studies in spite of their difficulty with factual knowledge. It also emerges that

the criterion of factual knowledge is not sufficient on its own to define dyscalculia, and it is essential to take into account the student's achievements in other types of arithmetic knowledge as well. In this respect our research sharpens the definitions of the two profiles and permits the implementation of additional research and intervention programs.

The combined results of the two experiments suggest a possible path for the development of arithmetic knowledge. Students with normal development (experiment 1) possess a hierarchy between three types of arithmetic knowledge, factual knowledge → procedural fluency → conceptual understanding. Phonological working memory and naming speed also contribute to achievements in factual knowledge, and executive functions of shifting and updating contribute to achievements in procedural fluency and conceptual understanding respectively. Significant difficulties in these cognitive abilities lead to difficulties in acquisition of arithmetic proficiency and the creation of profiles of GD and SD (experiment 2). The two profiles display very low achievements in factual knowledge compared to normal development. At the same time, while those with GD display difficulty further on in the course of arithmetic knowledge (in procedural and conceptual skills), those with SD have normal achievements later on. This apparently derives from the difference between the groups in normal executive functions. While those with GD have significant difficulties with executive functions, those with SD have normal executive functions which permit continued learning.