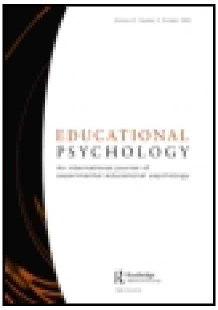

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Differences between Flemish and Chinese primary students' mastery of basic arithmetic operations

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The present paper investigates differences in the process of mastering the four basic arithmetic operations (addition, subtraction, multiplication and division) between Flemish and Chinese children from Grade 3 till Grade 6 (i.e. from 8 to 11 years old). The results showed, firstly, that Chinese students outperformed Flemish students in each grade but that difference in addition, subtraction and division skills between the groups decreased as grade increased. Secondly, the levels of mastery of the four skills varied between Chinese and Flemish students. Multiplication was relatively easier for Chinese students than for their Flemish peers as compared to the other skills (that is, the gap was larger). Third, low achievers experienced comparable learning difficulties in both countries, and higher achievers demonstrated their greater ability early on.

Keywords: basic arithmetic skills; fact retrieval; mathematics; Flemish; Chinese

Introduction

For more than 100 years, individual differences in numerical, arithmetical and other mathematical performance have been investigated by educational and psychological studies (Brownell, 1928; Geary, 2006; Thorndike, 1922; Thorndike & Woodworth, 1901). About 50 years ago, the first systematic cross-national study on difference in mathematics performance was conducted to explore the role of sociocultural differences (Husen, 1967). Since then, differences in mathematics performance due to learning under different educational systems have been confirmed in ongoing international assessments (TIMSS, PISA).

Moreover, a number of worldwide comparative studies have provided important information on the role of the educational systems adopted by specific cultures (Dowker, Bala, & Liloyd, 2008). Recently, an increasing number of studies have focused on both psychological and sociological explanations for differences in mathematical skills across countries (Imbo & LeFevre, 2009, 2011; Zhou et al., 2009). Since both Flemish and Chinese students show high performance in international mathematics performance indicator studies such as PISA (Prais, 2003), irrespective of differences in curriculum and/or instructional approach, it should be interesting to

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analyse mathematics skills between these two countries in more detail and identify differences. The present study endeavours to do so; however, as will be explained in detail below, it also goes beyond a general comparison. Previous studies in this area have mainly focused on two mathematical domains: numerical facility (or fact retrieval) and mathematical reasoning (Chein, 1939; Dowker, 2005; Thurstone & Thurstone, 1941). In the present study, the focus is on the mastery of fact retrieval skills, a prerequisite for solving everyday problems and a variety of arithmetical problem-solving tasks, for which children have to add, subtract, multiply and divide numbers as fast and accurately as possible. The present study explores whether the development of these basic arithmetic operations differs between Chinese and Flemish primary school children, at several levels of ability. In doing so, the current study addresses two research questions:

(1) Is there an impact of cultural background (e.g. language, curriculum, teaching practices) on students' development of basic arithmetic skills? And if so, are these differences apparent in low- or high-achieving children, and equally? If curriculum plays an important role, the differences between Chinese and Flemish can be supposed to decrease as grade increases, since the curriculum objectives are the same in both countries by the end of grade six. However, if language, for example, plays an important role and the other factors do not, no such age-related decrease in differences between Chinese and Flemish children will be found.
(2) Do cross-cultural differences vary across operations, considering school grades and students with low or high mathematical abilities? For example, is addition easier than division in both cultural settings?

Differences in the development of basic arithmetic skills

Basic arithmetic skills are defined here as the combination of arithmetical computation and a conceptual understanding of number relationships and arithmetical concepts, following previous studies (Baroody, 2006; Thurstone & Thurstone, 1941). In this section, we focus on the development and mastery of basic arithmetic skills by Flemish and Chinese primary school children.

Cultural differences between Flanders and China

Cross-national comparative studies of mathematics performance consistently show that East Asian children outperform Western children on numerical and arithmetical skills, and especially on addition and subtraction tasks (De Corte, Greer, & Verschaffel, 1996; Geary, Bow-Thomas, Fan, & Siegler, 1993; Robitaille & Travers, 1992). These differences in performance have been attributed to a number of cultural variables and processes, such as language (Colome, Laka, & Sebastian-Galles, 2010; Whorf, 1956) and educational system (Campbell & Xue, 2001; Geary, Bow-Thomas, Fan, & Siegler, 1996). However, previous studies have revealed cultural differences in learning not only in school-age children but also in preschoolers, suggesting that schooling is only one of the factors explaining these differences (Imbo & LeFevre, 2009, 2011; Siegler & Mu, 2008); additional explanations could involve, for example, linguistic differences (Colome et al., 2010).

Linguistic differences can potentially play a number of roles in learning. First, it has been argued that the (non-)transparency of the counting system of a language might influence working memory span in that language (Baddeley, 2000; Raghubar, Barnes, & Hecht, 2010), and as such also influence performance in mathematics. In this light, several studies have revealed the working memory advantage of about two digits for Chinese-speaking children compared to English-speaking children, helping to explain their higher performance on basic arithmetic tasks (Geary, Bow-Thomas et al., 1996; Stigler, Lee, & Stevenson, 1986). Second, previous studies have explored the role of specialised, maths-specific language in maths performance. According to Seron and Fayol (1994), the way numbers are represented in a language influences their processability and as such affects students' mathematical performance. The role of specific mathematical language is reflected in the triple-code model of Dehaene and his colleagues (Dehaene, 1992; Dehaene & Cohen, 1995), according to which there are three internal representations of numbers: an analogue magnitude system, a visual Arabic sketchpad and a verbal system. The verbal code in particular would be affected by the language used by students in a particular cultural setting.

Besides language, school-related variables may also play a role as a determinant of differences in mathematical performance. Differences in curriculum structure (e.g. the sequencing of curriculum topics), textbook design and didactic strategies adopted by teachers have been expected to affect the development and mastery of numerical facility (Geary, Salthouse, Chen, & Fan, 1996; Xin, 2007). If there are clear differences among students in opportunities to learn basic arithmetic skills during primary school, it can be expected that these students will evolve in different ways (in terms of factors like speed, timing and so on) in areas like the explicit procedural strategies used during the early years and memory retrieval strategies used in later years (Koshmider & Ashcraft, 1991; Siegler, 1988). Since school-related variables interact with language, we carried out a preliminary analysis of curriculum content, didactic approaches and time spent on mathematics weekly in Flanders and in China. The results of this preliminary analysis are summarised in Appendices 1a, 1b and 1c. There were no big differences on requirement of mathematics syllabi between Flanders and China; only one key difference was present, namely that the curriculum in China is clearly more demanding during the initial school grades (Grade 1 up to Grade 2) compared to that in Flanders. We therefore argue that compared to the apparent differences caused by language in the early years, differences in fact retrieval skills might mainly be explained by country differences in education and related variables.

Differences between low, average and high performers in both countries

The majority of comparative studies have focused solely on the development of basic arithmetic skills by 'normal'-achieving students (Wang & Lin, 2009), and little comparative research has been set up that systematically considers students with varying levels of mathematical skill (Desoete, Stock, Schepens, Baeyens, & Roeyers, 2009; Geary & Hoard, 2005). Therefore, the present study will consider the differences between low-, average- and high-performing children in both countries. Since previous studies indicate that students with mathematical learning difficulties show deficits in particular numerical skills (that is, arithmetic procedural skills, number fact retrieval, the concept of place value and number sense) and two domain-general processing skills (i.e. working memory and processing speed) (Chan & Ho, 2010), it is expected that students with poor mathematics skills will experience more difficulties executing basic number tasks that require automatisation of number fact retrieval from long-term memory than will students with strong mathematics skills (Desoete et al., 2009; Geary & Hoard, 2005). Thus, basic arithmetic skills can be considered equivalent to number fact retrieval skills. It will be interesting to see how differences in these skills interact with cultural variables.

Patterns in the mastery and development of the four basic arithmetic operations

Children learn to perform four basic arithmetic operations: addition, subtraction, multiplication and division. Several studies have indicated that these tasks differ in terms of difficulty level (Campbell, 1999; Siegler, 1996). Regarding addition, Fayol (1990) and Siegler (1996) state that addition skills are mostly the result of informal learning and develop along with children's acquisition of counting skills at the early stage of their school career, whereas multiplication skills are the results of formal learning. In addition, Campbell (1999) reveals that multiplication mediated large-number division problems, and Campbell (1997) underlines the fact that division memory is organised in terms of multiplicative relationships. All these research findings should be understood in terms of the sequencing sequence in which the operations are covered in the curriculum: addition, subtraction, multiplication and division.

Psychological studies indicate that multiplication and addition tasks are more often solved by fact retrieval than subtraction and division tasks (e.g. Campbell & Xue, 2001). In addition, Thevenot, Castel, Fanget and Fayol (2010) show that only high-achieving students use retrieval strategies to perform mental subtraction tasks. Moreover, studies from a neuropsychological perspective have revealed that while addition tasks rely on visuo-spatial processing, multiplication tasks build mainly on verbal processing (Imbo & LeFevre, 2010; Zhou et al., 2007). To sum up, studies have provided evidence for important differences between the development of four distinct basic arithmetic skills in young children.

The present comparative study conducts an analysis of the mastery and development of these four fact retrieval skills. Operating on the basis of known general differences in mastery of the four operations, a more fine-grained comparison – in relation to differences between countries, grades and mathematical ability levels – should constitute a step forward. Whatever differences are found will likely influence future decisions as to the design of the curriculum and the teaching and learning environment. For example, if multiplication is easier than addition for Chinese students but not for Flemish student. This implies that curriculum developers can place multiplication content earlier in textbooks in China than in Flanders, where multiplication content can be postponed until children's working span is good enough to recite multiplication tables.

Methodology

Sample

A total of 7247 Chinese students and 913 Flemish students, enrolled in Grades 3 to 6 in primary school, were involved in this study. The Flemish students came from 21 schools and the Chinese students from 20 schools in five different provinces and cities. After the test was administered (see below), all students were asked to provide gender and grade information. Descriptive statistics for grade and gender are presented in Table 1.

Procedure

All ability measures were obtained in the students' classroom setting, following a standard protocol. Participants were first tested on basic arithmetic skills, followed by an in-depth assessment of mathematical abilities. The test lasted about five minutes for the basic arithmetic operations test and 40–50 min for the mathematics abilities test.

Basic arithmetic skills

A standardised test of basic arithmetic operations (the Tempo Test Rekenen [TTR]; De Vos, 1992) was administered to both Flemish and Chinese children. The TTR is a 'timed' test consisting of 200 arithmetic problems. Test-takers have to solve as many additions (e.g. $5 + 2 = \ldots$), subtractions (e.g. $6 - 5 = \ldots$), multiplications (e.g. $2 \times 8 = \ldots$) and divisions (e.g. $16 \div 4 = \ldots$) and mixed exercises in five minutes (one minute per problem type). In this paper, we only include the results for the first four categories, not for mixed operations (see Appendix 1a).

Determining mathematical achievement levels

All students were also screened on general mathematical achievement, in terms of local curriculum requirements.

In Flanders, the students were assessed with the Kortrijk Arithmetic Test–Revised (Kortrijkse Rekentest Revision [KRT-R]; Baudonck et al., 2006), an untimed, standardised test on procedural calculations. KRT-R requires that children solve simple calculations in a number-problem format (e.g. 39 + 60 =) or word-problem format (e.g. 6 more than 48 is …). The psychometric value of the test has been demonstrated on a sample of 3246 children (Baudonck et al., 2006).

In China, children were tested with a test covering the new curriculum implemented in 2001 (Zhao, Valcke, Desoete, Verhaeghe, & Xu, 2011). The test has a good psychometric value, with alpha values ranging between .95 and .93.

Both the KRT-R and the Chinese test are based on the same constructs, measuring number-reading skills, mathematical lexicon, procedural knowledge, linguistic skills, mental representations, contextual skills, selection of relevant information, number sense and memory.

Table 1. Sample characteristics.

Country	Gender	Grade 3	Grade 4	Grade 5	Grade 6	Total
Flanders	Female	119	146	100	67	432
	Male	150	155	73	103	481
China	Female	872	852	847	917	3488
	Male	933	979	904	943	3759
Total		2074	2132	1924	2030	8160

These tests were used to distinguish between three groups of children: low-performing (25%), average-performing (50%) and high-performing groups (25%).

Curriculum content analysis

An in-depth analysis was done of relevant curriculum in both China and Flanders (see Appendix 1a). Arithmetic requirements were selected for both countries, and the similar content was separated and listed by grade (see Appendices 1a and 1c). In addition, a commonly used Chinese mathematics textbook series (*Shuxue*) was compared to a textbook series frequently used in Flanders (KOMPAS). Both textbook series are geared to the standards and curriculum that currently determine mathematics instruction in Flemish and Chinese primary education (respectively) and present the approaches used to teach the four arithmetic operations.

Data analysis

As a first step, the correlations between fact retrieval skills for addition, subtraction, multiplication and division were computed. Next, a 4 (grade) × 2 (country) × 3 (achievement level) MANOVA was conducted to evaluate differences between the four basic arithmetic skills (addition, subtraction, multiplication and division) of Flemish and Chinese students, taking into account different levels of mathematical achievement.[1] In the second step, ANOVAs were computed to compare the differences if the MANOVA in the previous studies was significant.

Then, a 4 (grade) × 2 (country) × 3 (achievement level) MANOVA was conducted on the six differences between each pair of numerical facilities (addition and subtraction, addition and multiplication, addition and division, subtraction and multiplication, subtraction and division, multiplication and division).[2] Next, in the cases where the MANOVAs performed in steps 1 and 2 were significant, ANOVAs were carried out to study the nature of the differences. Simple mean values were contrasted by means of the HSD procedure. A significance level of $p < .01$ was set for all analyses.

Results

Descriptive results

The correlations between the four arithmetic operations were computed for both countries. Table 2 shows how mastery of all four skills is strongly correlated in both countries (see Table 2).

Differences between countries, grades and mathematics achievement levels, and interaction effects on each skill

In this section, the four basic arithmetic skills are considered together. There were no significant gender differences either across the entire sample or within countries.[3]

To identify differences between countries, grades and achievement levels, MANOVA was carried out with the four basic arithmetic operations as dependent variables. There were significant multivariate differences between countries ($F_{(4, 8141)} = 593.14$, $p < .01$, $\eta^2 = .23$), grades ($F_{(12, 21539.353)} = 84.64$, $p < .01$, $\eta^2 = .04$)

Table 2. Correlations between the fact retrieval skills.

	Addition	Subtraction	Multiplication	Division
Addition	–	.77**	.70**	.66**
Subtraction	.75**	–	.72**	.72**
Multiplication	.61**	.78**	–	.82**
Division	.60**	.76**	.79**	–

Notes: Correlations for Flemish students are presented above the diagonal, and correlations for Chinese student are presented below the diagonal. $^{*}p<.05$. $^{**}p<.01$.

and mathematics achievement level ($F_{(8,\ 16,282)} = 96.65$, $p < .01$, $\eta^2 = .05$). Also, interactions for country × grade ($F_{(12,24539.353)} = 10.17$, $p < .01$, $\eta^2 = .01$) and grade × achievement level ($F_{(24,28401.77)}$=10.16, $p < .01$, $\eta^2 = .01$) were present. The effect sizes for country × grade ($\eta^2 = .01$) and grade × ability ($\eta^2 = .01$) were small, while that for country ($\eta^2 = .23$) was of a medium size (Green, Salkind, & Akey, 2000).

To identify differences for each individual skill between countries, grades and mathematics achievement levels, univariate analyses (ANOVAs) were computed for each. As showed in Table 3, the score for each was higher for Chinese than for Flemish students and for older than for younger students (i.e. higher grade than lower grade). Higher achievers did better than lower achievers on fact retrieval skills. All *p*-values were smaller than .01, showing significance.

Table 3. Comparison of the fact retrieval skills in different groups.

Source	Subgroup		Additions *M* (SD)	Subtractions *M* (SD)	Multiplications *M* (SD)	Divisions *M* (SD)
Country	Flemish	Grade 3	16.48 (4.58)	15.7 (4.09)	14.9 (4.1)	10.03 (5.48)
		Grade 4	20.44 (4.33)	19.25 (3.91)	18.53 (4.01)	15.48 (5.23)
		Grade 5	24.45 (3.86)	22.40 (3.72)	21.16 (3.87)	18.73 (5.12)
		Grade 6	26.51 (4.25)	24.97 (3.88)	23.33 (4.37)	21.19 (5.48)
	Chinese	Grade 3	28.79 (8.74)	24.28 (10.22)	25.99 (9.82)	16.2 (10.41)
		Grade 4	30.44 (10.16)	26.34 (10.6)	29.41 (10.74)	21.9 (11.86)
		Grade 5	34.56 (5.97)	30.59 (7.16)	34.3 (6.08)	28.29 (9.52)
		Grade 6	35.64 (6.29)	31.29 (9.57)	34.42 (9.15)	31.72 (10.28)
Achievement level	Lower achiever	Grade 3	22.53 (9.22)	17.81 (9.58)	19.82 (10.37)	9.91 (8.00)
		Grade 4	26.81 (10.15)	22.46 (9.99)	25.21 (10.99)	16.86 (10.71)
		Grade 5	32.07 (6.78)	27.05 (7.05)	32.09 (6.49)	24.41 (8.66)
		Grade 6	33.96 (6.17)	28.5 (9.73)	32.14 (9.88)	27.91 (10.7)
	Average achiever	Grade 3	27.49 (8.43)	23.3 (9.13)	25.07 (8.95)	15.76 (9.3)
		Grade 4	29.42 (9.57)	25.69 (9.68)	28.22 (10.05)	20.87 (10.73)
		Grade 5	33.41 (6.39)	29.94 (7.07)	33.20 (6.88)	28.06 (8.97)
		Grade 6	34.51 (6.61)	30.20 (9.16)	33.10 (9.45)	30.38 (10.19)
	Higher achiever	Grade 3	31.3 (9.11)	28.31 (9.82)	28.23 (10.01)	20.20 (11.16)
		Grade 4	30.67 (10.97)	27.78 (10.87)	30.12 (11.31)	25.81 (11.6)
		Grade 5	35.71 (5.87)	32.43 (7.07)	33.94 (7.62)	29.09 (11.02)
		Grade 6	36.59 (6.87)	34.24 (8.56)	35.66 (8.22)	34.77 (9.24)

Note: Add: Addition; Sub: subtraction; Mul: multiplication; Div: division.

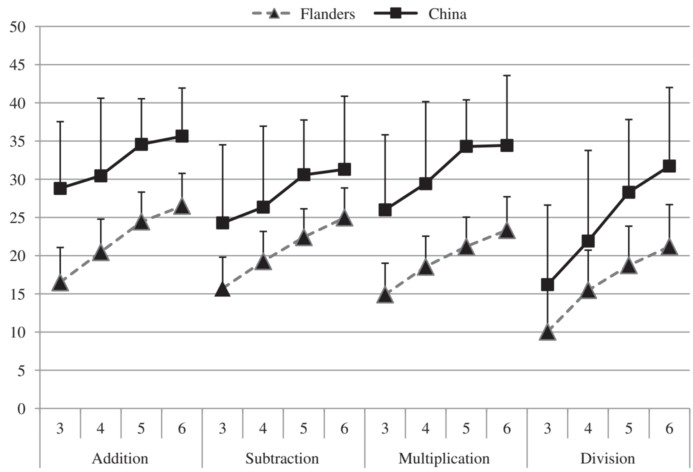

Figure 1. Number of correctly solved items for four basic arithmetic operations, at each grade level in Flanders and China.
Note: The error bar represented for the standard deviation.

Do students in both countries attain the same level of performance in basic arithmetic skills by the end of elementary school? The interaction of country × grade was studied to answer this question. Results are shown in Figure 1. Significant interaction effects were found for addition ($F_{(3,8144)} = 7.06$, $p < .001$, $\eta^{2=}.003$) and division ($F_{(3,8144)} = 9.13$, $p < .001$, $\eta^{2=}.003$). There was no significant interaction for subtraction ($F_{(3,8144)} = 2.68$, $p = .045$, $\eta^{2=}.001$) or multiplication ($F_{(3,8144)} = 2.53$, $p = .055$, $\eta^{2=}.001$). And when the effect of grade was examined separately for Flemish and Chinese children, the dataset revealed an unstable improvement by grade on addition and division for Chinese students and a stable improvement for the Flemish sample (see Figure 1). As Figure 1 shows, the difference between Chinese and Flemish students on addition and subtraction decreases with age or grade (all ps < .001), but not for multiplication and division. For the Chinese students in Grade 5, the scores on subtraction ($M = 30.28$) and multiplication ($M = 34.29$) did not differ significantly from score on subtraction ($M = 31.29$, $p = .162$) or multiplication ($M = 34.42$, $p = .697$) in Grade 6. For the multiplication and division results, refer to Figure 1.

To find differences between low, average and good mathematical achievers, the interaction of grade × achievement level was analysed with ANOVA. There was a significant interaction effect for addition ($F_{(6,8144)} = 18.61$, $p < .001$, $\eta^2 = .014$), subtraction ($F_{(6,8144)} = 12.09$, $p < .001$, $\eta^2 = .009$), multiplication ($F_{(6,8144)} = 14.93$, $p < .001$, $\eta^2 = .011$) and division ($F_{(6,8144)} = 11.09$, $p < .001$, $\eta^2 = .008$). To examine this interaction, the file was split by achievement level and a ANOVA was run for grade. As a result, the difference between grades for average and lower achiever became smaller for subtraction and multiplication. For lower and average achievers in Grade 5, scores on subtraction and multiplication were not significantly different from those of their peers in Grade 6. Similarly, for higher achievers in Grade 3, scores on addition and subtraction were not significantly different from those of higher achievers in Grade 4.

Differences between countries, grade, achievement level and interaction effects on the basic arithmetic skills

Do the four basic arithmetic skills have different mastery levels? In this section, we explore the differences between the four arithmetic skills. In the previous section, as Table 3 reveals, Flemish and Chinese students differed in terms of the difficulty they had with the four arithmetic skills. Flemish students solved more additions (M = 21.16) in one minute than subtractions (M = 19.86), multiplications (M = 18.85) or divisions (M = 15.55) and more subtractions than multiplications. The results differed for Chinese students: additions (M = 32.36), multiplications (M = 31.05), subtractions (M = 28.12) and divisions (M = 24.54). In order to check mastery levels, a paired-samples t-test was conducted to compare pairwise the difference between each pair of the four basic arithmetic skills for Flemish and Chinese students in each grade (see Table 4). All *t*-tests were significant at the .001 level in each of the separated subsamples. In general, both Chinese and Flemish students achieved significantly higher results for additions compared to the other tasks and also significantly higher results for subtractions than for divisions. Moreover, students performed significantly better on multiplication than on division tasks. These results are in line with the order in which topics are introduced in the curricula, except for the multiplication results of the Chinese students. As Table 1a in the Appendix shows, addition and subtraction are taught to both Flemish and Chinese students from Grade 1, followed by multiplication and division from Grade 2.

Do additions, subtraction, multiplications and divisions have the same difficulty level in both countries? In order to explore whether the four basic arithmetic skills have the same difficulty level in both countries, a MANOVA[4] was conducted with country, grade and mathematics achievement level as independent variables and the differences between the six pairs of basic arithmetic skills as dependent variables. Results revealed main effects for country ($F_{(3,\ 8142)} = 148.67$, $p < .01$, $\eta^2 = .05$), grade ($F_{(9,19815.639)} = 31.32$, $p < .01$, $\eta^2 = .01$) and mathematics achievement ($F_{(6,16,284)} = 49.63$, $p < .01$, $\eta^2 = .02$), and interactions between country and grade ($F_{(9,19815.639)} = 12.70$, $p < .01$, $\eta^2 = .005$) and between grade and mathematics ability ($F_{(18,\ 23029.54)} = 6.69$, $p < .01$, $\eta^2 = .005$). Given the significance of the overall test, the univariate main effects and interactions were then examined step by step.

Are addition, subtraction, multiplication and division equally difficult for Chinese and Flemish students? Significant univariate main effects for country were obtained for five pairs, the only exception being subtraction and division ($F_{(1,8144)} =$ 6.60, $p = .010$, $\eta^2 = .001$), where the difference was the same for Flemish students (M = 4.31) and Chinese students (M = 3.58) (p = .022) (see Figure 2). Chinese students achieved 2.90 points higher in multiplication than in subtraction, while Flemish students scored 1.01 points higher in subtraction than in multiplication (see Figure 2). The curricula cover them in the same order in both countries. Thus, multiplication tasks seem to have a different position in the respective curricula. The position of multiplication and subtraction results is roughly reversed.

Do additions, subtractions, multiplications and divisions have the same difficulty level for all grades? Significant univariate main effects were obtained for three pairs of differences: between addition and division ($F_{(3,8144)} = 43.24$, $p < .01$, $\eta^2 = .016$), subtraction and division ($F_{(3,8144)} = 75.05$, $p < .01$, $\eta^2 = .027$), and multiplication and division ($F_{(3,8144)} = 69.87$, $p < .01$, $\eta^2 = .025$). (see Table 4 for all results.)

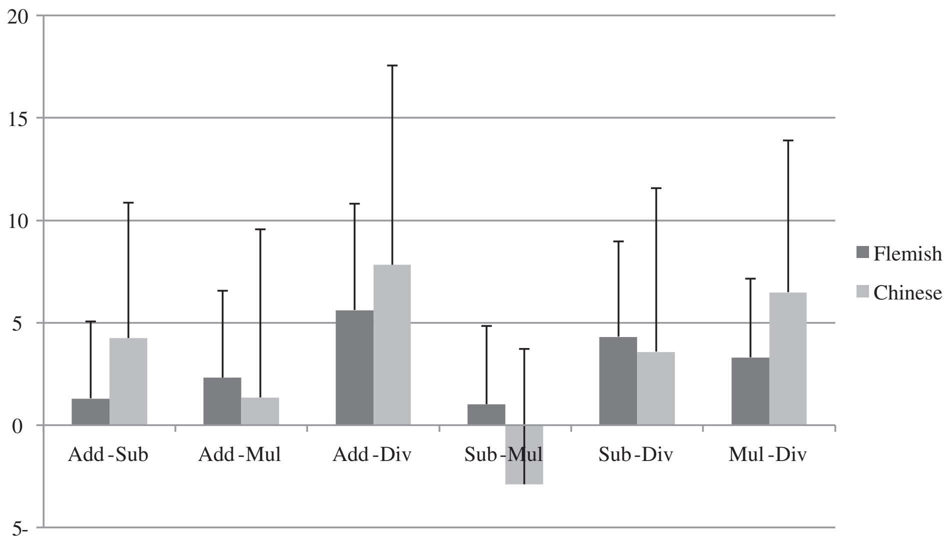

Figure 2. Difference between each of four arithmetic operations for Flemish and Chinese students.
Notes: Add: Addition; Sub: subtraction; Mul: multiplication; Div: division. The error bar represented for the standard deviation.

Students became more familiar with division, which they were still learning throughout the grades under study, as compared to the other operations (see Appendix 1a).

Do addition, subtraction, multiplication and division have the same difficulty level for students at different achievement levels? Significant univariate main effects were obtained for all pairs except addition and multiplication ($F_{(2,8144)}$ = .37, p = .373, η^2 = .000) and subtraction and division ($F_{(2,8144)}$ = 3.140, p = .04, η^2 = .001). There were no significant differences between lower, average and higher achievers for these pairs.

Do addition, subtraction, multiplication and division have the same difficulty level for both countries across grades? The interaction of country and grade was entered into the univariate analyses. Significant interactions were found between five pairs: addition/multiplication ($F_{(3,8144)}$ = 10.89, p < .001, η^2 = .004), addition/division ($F_{(3,8144)}$ = 27.55, p < .001, η^2 = .004), subtraction/multiplication ($F_{(3,8144)}$ = 6.64, p < .001, η^2 = .002), subtraction/division ($F_{(3,8144)}$ = 30.32, p < .001, η^2 = .011) and multiplication/division ($F_{(3,8144)}$ = 15.25, p < .001, η^2 = .006). Next, the file was split by country to examine the interactions. The results showed first that the scores for addition/division, subtraction/division and multiplication/division decreased with grade increase for Chinese students (ps < .001). In contrast, while for Flemish students in Grade 3, scores on these pairs were significantly higher than the scores of students in Grades 4, 5 and 6 (ps < .01), there were no significant differences for Flemish students between Grade 4, 5 and 6 (ps < .05).

Second, absolute scores for subtraction/multiplication decreased with grade for Chinese students (ps < .01) but not for Flemish students (ps < .05).

Table 4. Differences in interaction effect between fact retrieval and achievement level.

Source	Subgroup		Add-Sub *M* (SD)	Add-Mul *M* (SD)	Add-Div *M* (SD)	Sub-Mul *M* (SD)	Sub-Div *M* (SD)	Mul-Div *M* (SD)
Country	Flemish	Grade 3	.78 (4.23)	1.58 (4.80)	6.45 (5.95)	.8 (4.06)	5.67 (4.77)	4.87 (3.79)
		Grade 4	1.19 (3.58)	1.91 (4.28)	4.96 (5.01)	.71 (3.72)	3.77 (4.39)	3.05 (3.62)
		Grade 5	2.05 (3.06)	3.29 (3.5)	5.72 (4.33)	1.24 (3.93)	3.67 (4.59)	2.43 (3.69)
		Grade 6	1.54 (3.75)	3.18 (3.56)	5.32 (4.86)	1.64 (3.38)	3.78 (4.58)	2.14 (3.65)
	Chinese	Grade 3	4.51 (7.25)	2.8 (8.83)	12.59 (9.45)	−1.72 (6.47)	8.07 (7.8)	9.79 (7.54)
		Grade 4	4.09 (5.91)	1.02 (8.52)	8.54 (9.89)	−3.08 (7.84)	4.44 (8.57)	7.52 (7.66)
		Grade 5	3.97 (5.25)	.27 (6.13)	6.28 (8.29)	−3.71 (6.06)	2.30 (7.11)	6.01 (6.81)
		Grade 6	4.35 (7.66)	1.23 (8.77)	3.92 (9.01)	−3.13 (5.68)	−.43 (5.61)	2.69 (5.59)
Achievement level	Lower achiever	Grade 3	4.71 (7.74)	2.71 (9.53)	12.61 (8.77)	−2.01 (6.55)	7.9 (6.81)	9.91 (7.23)
		Grade 4	4.35 (6.27)	1.59 (9.35)	9.95 (9.82)	−2.75 (8.32)	5.6 (8.22)	8.35 (7.76)
		Grade 5	5.03 (4.95)	−.01 (5.70)	7.66 (7.31)	−5.04 (5.81)	2.64 (6.49)	7.68 (6.25)
		Grade 6	5.46 (8.37)	1.82 (9.37)	6.05 (9.29)	−3.64 (5.9)	0.59 (5.75)	4.23 (5.44)
	Average achiever	Grade 3	4.19 (7.06)	2.42 (8.31)	11.73 (8.85)	−1.77 (6.09)	7.54 (6.88)	9.31 (6.63)
		Grade 4	3.73 (5.77)	1.2 (8.39)	8.55 (9.91)	−2.53 (7.96)	4.82 (8.74)	7.35 (7.36)
		Grade 5	3.47 (4.89)	.2 (5.82)	5.35 (6.97)	−3.26 (5.79)	1.88 (5.73)	5.14 (6.11)
		Grade 6	4.31 (7.48)	1.41 (8.67)	4.13 (8.78)	−2.91 (5.62)	−.18 (5.48)	2.72 (5.05)
	Higher achiever	Grade 3	2.99 (6.12)	3.07 (7.45)	11.11 (10.68)	.08 (6.15)	8.12 (9.35)	8.03 (8.77)
		Grade 4	2.89 (4.85)	.56 (5.34)	4.86 (6.90)	−2.33 (5.33)	1.97 (5.84)	4.3 (6.32)
		Grade 5	3.28 (5.53)	1.77 (6.50)	6.61 (10.19)	−1.51 (6.36)	3.34 (9.16)	4.85 (7.70)
		Grade 6	2.34 (5.92)	.92 (6.94)	1.82 (7.54)	−1.42 (5.36)	−.53 (5.86)	.89 (5.80)

Notes: Add: Addition; Sub: subtraction; Mul: multiplication; Div: division.

Third, for addition/multiplication, Flemish students in Grades 3 and 4 achieved higher than students in Grades 5 and 6 (ps < .01), while Chinese students in Grades 3 and 5 achieved higher than students in Grades 4 and 6 (ps < .01).

Do addition, subtraction, multiplication and division have the same difficulty level for students of different achievement level across grades? With regard to the interaction of grade and achievement level, significant univariate main effects were obtained for five pairs: addition/multiplication ($F_{(6,8144)} = 4.17$, $p < .001$, $0^2 = .003$), addition/division ($F_{(6,8144)} = 11.05$, $p < .001$, $\eta^2 = .008$), subtraction/multiplication ($F_{(6,8144)} = 6.35$, $p < .001$, $\eta^2 = .005$), subtraction/division ($F_{(6,8144)} = 13.72$, $p < .001$, $\eta^2 = .010$) and multiplication/division ($F_{(6,8144)} = 6.38$, $p < .001$, $\eta^2 = .005$). When the file is split by grade to examine the interaction effect, different patterns can be found by achievement level at different grades.

Two results are especially important here. First, in Grade 6, for the pairs of addition and division, subtraction and multiplication, subtraction and division, and multiplication and division, there were significant differences between achievement groups (ps < .01) but not for the lower grade levels. Second, for the pair of addition and multiplication, there was no significant difference for by achievement level in Grades 3, 4 or 6 (ps < .05). The results revealed that differences between lower, average and higher achievers increased with the grade on all pairs except for two: addition and multiplication and addition and subtraction.

Discussion

The present comparative study of Flemish and Chinese children's basic arithmetic skills revealed several cross-cultural differences between children. The first research question related to the impact of cultural background on students' development of the four basic arithmetic operation skills. The second compared the differences between mastery of each of these operations by country, grade and general mathematics achievement level.

Differences in the four basic arithmetic skills

Chinese students outperformed Flemish students in the four basic arithmetic skills

The results of this study indicate that Chinese primary school students outperformed Flemish students on the four basic arithmetic skills. This finding is in line with other research indicating that East Asian students outperform their Western peers on these skills (Imbo & LeFevre, 2009, 2011). The pedagogical content covered by the respective curricula in Flanders and China was comparable (see Appendices 1b and 1c). As can be seen in Appendix 1b, teachers in both countries made use of the concept of place value to teach addition and subtraction and valued the tool of the number line to help the children understand the meaning of place value. For example, addition was taught by separating numbers into different pairs of small numbers: 8 was the result for 4 + 4 and also for 2 + 6, etc. (see Appendix 1b). In both countries, in other words, the students were required to understand that larger numbers can be achieved by combining smaller numbers. Similarly, in the case of multiplication, students needed to understand the meaning of multiplicational notation, as for example that 5 × 2 is five times (groups of) two. In addition, children in both countries had to memorise and be able to recite the multiplication table. Moreover, the teaching time devoted to fact retrieval in Flemish and Chinese students was comparable: there were among four or five lessons per week.

Yet the learning requirements are much more demanding in China for the first two grades of school (Grades 1 and 2), as can be concluded from Appendix 1a. For example, Chinese students in Grade 1 have to be able to complete exercises with numbers up to 100 in Grade 1, whereas Flemish students only solve exercises with numbers smaller than 20 at that age. In Grade 2, there are similar differences with Flemish students needing to be able to handle exercises with numbers up to 100 and Chinese students calculating up to 10,000. Such differences continue in the later grades, making curricula hard to compare between the countries because Chinese children are getting a more demanding education in fact retrieval and other mathematic skills.

The differences between Chinese and Flemish students on addition decreased with grade, differences on division increased but not for multiplication and subtraction

The results of the current study indicate that the content of the curriculum for each grade had some degree of impact on the students' performance. Specifically, the analyses showed a significant association between grade and children's performance in addition, subtraction and division. Obviously, the students' grade played an important role in the development of these basic arithmetic operations. But how about the interaction between grade and country?

The differences between Chinese and Flemish students decreased in the higher grades for addition. Addition was basic operation and students got familiar with the simple addition operation with the increasing of grade.

One interesting result can be seen with regard to the multiplication tasks, where no significant interaction effect of country x grade was observed. This result indicates that the difference in multiplication skills between Flemish and Chinese students does not decrease as the children get older, in contrast to the case for the other fact retrieval tasks, addition and subtraction (see Figure 1). Though Zhou et al. (2006) state that two types of strategies can be used to complete simple arithmetical tasks, namely procedural strategies and rote verbal memory strategies, the current findings suggest that both Chinese and Flemish students would rather apply rote memory strategies and tackle these problems by memorising multiplication facts. This is confirmed by the curriculum analysis (Appendix 1b), which shows that in both countries, rote verbal strategies are applied to teach the multiplication table.

The differences between Chinese and Flemish student on division increased in the higher grade. Firstly, the difference can be partly be explained by the differences in curriculum content between the two countries (see Appendix 1a). From Grade 2, Chinese student have to do the division within multiplication table while Flemish student does not have division lesson. Later, the Flemish students' knowledge of division is almost one year delayed than Chinese students in Grade 3 and 4. In Grade 5 and 6, Chinese students focus on division of decimal and fraction while Flemish students focus on the division of fraction and decimal with whole number as dividend. Secondly, the division operation is mediated by the multiplication (Campbell, 1997, 1999). On one hand, multiplication for both cultures is not changed with the grade; on the other hand, the knowledge division for Chinese increases more quickly than Flemish with grade. Then, the difference on division increased with grade.

Lower achievers remain below-average performers, while higher achievers master the facts about arithmetic at a younger age

In the present study, we distinguished between low-, average- and high-performing students. As expected, a main effect of achievement level was found among our participants, in which the higher achievers outperformed the lower achievers on fact retrieval tasks. However, the main question was whether students with different ability levels would continue to perform differently as they got older.

With regard to the lower achievers, the subtraction and multiplication scores did not increase from Grade 5 to Grade 6. For the group of high achievers, in contrast, the students in Grade 3 already did equally well on addition and subtraction as the children in Grade 4. In both countries, the most demanding aspects of learning to complete the simple operations of addition and subtraction were finished by this stage. As early as Grade 3, these students are expected to be able to calculate addition problems with sums up to 1000 and subtractions with minuends up to 100. Again, in both countries, the curriculum objectives change from integer to the decimal calculation and do not provide further integer calculation strategies for the higher achiever until Grades 5 and 6. And importantly, at this stage, the difference between these higher achievers and the other students increased again.

Previous studies have shown that mental representations to solve elementary number combinations are different between high- and low-achieving students (Desoete et al., 2009; Pitta & Grey, 1997). Specifically, low achievers' mental representations are strongly associated with the procedural aspects of numerical processing, while the high achievers' mental representations are focused instead on abstractions (Pitta & Grey, 1997).

Differences in the six pairs for each two of four basic arithmetic skills

The four basic arithmetic skills have different positions in terms of difficulty for children in China and Flanders

In Flanders, students performed best on addition tasks, followed by subtraction, multiplication and division tasks. In China, additions were also the easiest, followed (in contrast) by multiplication, subtraction and division. This order of degree of mastery obviously reflects curricular arrangements in general in the two countries (see Appendix 1a). In both, children are first taught addition skills, continue with subtraction and multiplication and learn division skills last. However, it remains not completely clear why Chinese students have fewer problems with multiplication than with subtraction.

Perhaps, this difference can be explained in part or completely by the linguistic differences between the countries. Previous studies have stressed the importance of linguistic transparency in learning the counting system of a language (Dowker, Bala, & Liloyd, 2008). In this context, the Chinese language around reading numbers is very transparent and consistent. The way one pronounces a number word is the same as how one writes the Arabic number. For example, in Mandarin Chinese, the number 72 is read as *qi shi er* 'seven ten two', in which *qi* represents the number seven, *er* refers to the number two and *shi* refers to the place value 10. In Flemish (also known as Belgian Dutch), on the other hand, the reading of numbers is inconsistent with their Arabic number representation: for instance, 72 is read as *tweeënzeventig* 'two-and-seventy'. This might help explain why Chinese children perform better in multiplication tasks than in subtraction tasks, whereas the opposite order is found in Flemish children. In other words, thanks to a more straightforward linguistic system, Chinese children seem to apply retrieval strategies quicker than Flemish students (Imbo & Lefevre, 2009). For example, it is easier for Chinese students to remember a formula like 'nine multiplied by nine is 81' (*jiu jiu ba shi yi*) while it is a little more difficult for Flemish students to remember the result for *eenentachtig*.

Flemish children improve at a stable rate for the four operations across grades, whereas students in China reach higher difficulty levels in basic arithmetic skills at younger age and then slow down

An interaction effect of grade × country was found in the comparison of results for addition vs. multiplication, addition vs. division, subtraction vs. multiplication, subtraction vs. division and multiplication vs. division.

For Chinese students, the differences between three division comparisons (addition/division, subtraction/division and multiplication/division) decreased as grade increased. However, for Flemish students, the differences between division and the other operations did not change with grade. This implies that improvement in addition, subtraction, multiplication and division proceeded at a steady rate for Flemish students (see Figure 1); whereas for the Chinese students, the improvement in division was larger (see Appendix 1a). This might be explained by the fact that the curriculum requirements for Flemish students improve stably in each grade, while Chinese students are required to reach a higher mastery level at a lower grade.

Difference in addition/subtractions and addition/multiplications was not significant for low, average or high achievers, across grades

The interaction of grade × achievement level was only significant for the pairs of addition/multiplication, addition/division, subtraction/multiplication, subtraction/division and multiplication/division. Also, a difference was found only in Grade 5 for the pair of addition and multiplication between lower, average and higher achievers. This implies that the difference between addition/multiplication and addition/subtraction was more stable than the others. There is little background literature to help us understand this result; thus, additional research is needed to replicate it and look for the reasons.

Conclusions, limitations and future study

The present study reflects a number of limitations that should be considered to improve future research in this area. First, future research needs to go beyond the level of mathematics *learning* per se and explore the differences in the actual processes and strategies being adopted by students doing math work in different cultural settings.

Second, the 'cultural' dimension here was approached in a rather general way. Besides the focus on language differences, only a few curriculum-related differences were considered (curriculum content; basic didactical approaches and timing). Other factors should be considered in an explicit way to better understand the effects of cultural differences on math learning (e.g. the actual teaching approach, homework, shadow education and the role of parents).

Third, among the higher achievers, Flemish students obtained better improvement for the four arithmetic skills during school grades later than those considered here. This is probably due to the Chinese students' attaining a ceiling in the early grades. Fourth, both Flanders and China are highly ranked in the PISA list. It could be interesting to involve other countries in the cross-cultural studies in order to better capture and explore critical performance differences.

Despite the limitations mentioned above, the present study introduces a number of new directions for study. First, we have confirmed that Chinese students outperform Flemish students in four basic arithmetic (fact retrieval) skills, but also that with more schooling, the difference decreases for addition, subtraction and division. This might conceivably be explained by differences in curriculum. Second, although curriculum in both countries is presented in the order addition, subtraction, multiplication, division, our data suggest that multiplication tasks have different difficulty levels for Flemish and Chinese students. This is not a result of curriculum or pedagogical approach, but might be explained by linguistic difference, which in turn might indicate that in China, multiplication can be taught at an even younger age.

Third, we found striking differences between poor, average and good mathematics performers and showed that poor performers do not make up their deficits over time. Additional research employing a longitudinal design is needed to better understand the difference in developmental patterns between students at these different performance levels.

Notes

1. Since four tests were done for the univariate here and we required an experiment-wise alpha rate of .01, we divide by four to get an acceptable confidence level for each of the four tests; therefore, we set an alpha level of $p < .003$. With a more lenient criterion of .05 (and a greater probability of Type I error), two other univariate tests would have been significant. The same criterion is adopted for this analysis.
2. The same reason as before, we set an alpha level of $p < .002$. With a more lenient criterion of .05 (and a greater probability of Type I error), two other univariate tests would have been significant. The same criterion is adopted for this analysis.
3. MANOVA confirmed that no main effect of gender and no interaction effects were found (country × gender, maths abilities × gender, grade × gender, for addition, subtraction, multiplication, division and mixed calculations).
4. MANOVA revealed that there were no interaction effects between mathematics ability and country or grade for the four arithmetic skills and six pairs of differences between operations.

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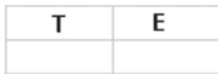
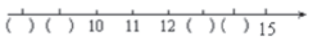
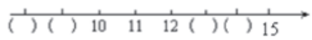
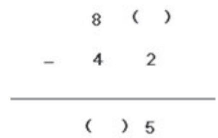
Appendix 1a. Comparison of the mathematics curriculum of Flanders and Mainland China

Domain	Number		Addition		Subtraction		Multiplication		Division	
Country	Flanders	China	Flanders	China	Flanders	China	Flanders	China	Flanders	China
Grade 1	1–20	<100	Sum < 10	sum < 100	minuend < 10	minuend < 20	–	–	–	–
Grade 2	1–100	<10,000	Sum < 100	sum < 10,000	minuend < 20	minuend < 10,000	Multiplication table	Multiplication table	–	Multiplication table
Grade 3	1–1000	Fraction + Decimal	Sum < 1000 Decimals	sum < 10,000	minuend < 100 decimals	minuend < 10,000	Multiplying by 10 and 100 1 digit * 2 digit 1 digit * 3 digit	Multi-digit * 1-digit 2-digit * 2-digit	Multiplication table; Division with remainder (divider < 10)	Division With Remainder; Divisor is 1-digit
Grade 4	1–100,000	100 000 000	Sum < 100,000		minuend < 1000		Multiplying by 5 and 50	3-digit * 2-digit	Division with remainder (all)	Divisor is 2-digit
Grade 5	1–10,000,000	Multiple and factor	Sum < 1,000,000,000 fractions	Decimal	<100,000 fractions	Decimal	Multiplying by 1 000 and 10 000 Fraction * whole number Decimal * whole number	Decimal	Fraction : whole number Decimal : whole number	Decimal
Grade 6	1–100,000,000	Negative number	Sum < 1 000,000,000	Fraction	<1,000,000,000	Fraction	Fraction * fraction Decimals	Fraction	Fraction : fraction Decimal : decimal	Fraction

Appendix 1b. Similarities and differences in pedagogical content in Flanders and China

	Flanders	China
Number	Place-value concept  	Place-value concept  
Addition	Eg. 8=4+4=2+6=1+7…. Eg. 17+5=17+3+2	Eg. 8=4+4=2+6=1+7… Eg. 17+5=17+3+2
Subtraction	Eg. TE-E=TE TE-T=E Eg. 5+6=11->11-6=5 Eg. 14-2=12 14-12=2	
Multiplication	Recite 5 X 2 is five times two 5 X 2 = 2+2+2+2+2	Recite 5 X 2 is five times two 5 X 2 = 2+2+2+2+2
Division		

Appendix 1c. Teaching time in Flanders and China weekly in spent in mathematics education

Country	Flanders	China
Lessons duration	50 min	40 mins
Grade 1	5 lessons	3-4 lessons
Grade 2	5 lessons	3-4 lessons
Grade 3	5 lessons	4-5 lessons
Grade 4	5 lessons	4-5 lessons
Grade 5	5 lessons	4-5 lessons
Grade 6	5 lessons	4-5 lessons