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Early Math Competence in Students with Autism

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Abstract : *Previous studies reported that a substantial number of students with autism spectrum disorder (ASD) encounter challenges in mathematics as they advance through their education. The present study evaluates the mathematical competence of 17 students diagnosed with ASD who were recruited from first through fourth grades in 12 different mainstream schools. The results were compared with those from other 17 students without ASD, matched one-to-one by sex and school (grade and classroom). In general, the students with ASD in this study exhibited greater difficulties in mathematics than their peers without ASD. These difficulties were particularly noticeable in fourth graders, although they could be observed earlier in informal skills. Many students with ASD in the sample struggled with informal calculation and concepts, as well as with all formal categories considered, particularly calculation and concepts. These findings may be relevant for early teaching interventions and for the development of future mathematical learning supports for students with ASD.*

According to the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V; American Psychiatric Association, 2013), autism spectrum disorder (ASD) is a neurodevelopmental condition typically characterised by: (a) persistent impairments in communication and social interactions, and (b) restrictive and repetitive patterns of behaviour, interests or activities. However, it is important to note that these characteristics are very far from being homogeneously presented in people with ASD (e.g., Georgiades et al., 2013). This variability has a corresponding impact on academic achievement (Keen et al., 2016). Specifically, mathematical performance is reflective of this heterogeneity, as reported by King et al. (2016). About 22% of students diagnosed with ASD without intellectual disability are expected to experience mathematical learning disabilities (Mayes & Calhoun, 2006).

Previous studies have yielded mixed results regarding the mathematical proficiency of students with ASD, with outcomes differing depending on the age of the participants (Bullen et al., 2022; Chen et al., 2019; Titeca et al., 2014; Wei et al., 2015). Thus, according to Titeca et al. (2014), early numeracy skills of children diagnosed with ASD without intellectual disability are comparable to those of their peers without ASD during the preschool years. Among pre-numerical skills, verbal subitizing and counting have been identified as having greater predictive value for subsequent mathematical proficiency. Specifically, verbal subitizing is claimed to have a higher predictive value in children with ASD than in typically developing ones.

As participants' age increases, the effects of the heterogeneous symptoms of ASD appear to manifest in the form of different achievement profiles. Wei et al. (2015) explored the age range of 6–9 years old and identified four profiles among 130 children with ASD based on reading, mathematical, cognitive and social skills. Of particular interest is mathematical competence, as only 38.5% of the students demonstrated average achievement. The authors also reported on other three groups of students. The first group (9.2% of the sample) had hyperlexia and scored one standard deviation lower than average in passage comprehension, applied problems, and calculation categories. The second group (20% of the sample) had hypercalculia, with an average score in calculation skills but lower scores in other categories, including

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mathematical ones. The third group (32.3% of the sample) scored lower than two standard deviations from the average across all dimensions. In the age range of 7 to 12 years old, Chen et al. (2019) identified two academic achievement profiles among a sample of 114 male children with ASD without intellectual disability. While the authors found that the average achievement scores were within the normal range, they observed that the first group (36.8% of the sample) demonstrated poorer mathematical skills than reading skills, while the second group (63.2% of the sample) exhibited superior math skills compared to reading skills. In their study of 78 children with ASD without intellectual disability between the ages of 8 and 16 years old, Bullen et al. (2022) identified two distinct profiles. The first group, comprising 70% of the sample, demonstrated low-average achievement, while the remaining 30% exhibited above-average mathematical skills and normative reading scores. Children in the former group displayed low achievement in problem solving and reading but normative levels of calculation. According to the authors, the mathematical difficulties of some children in this group may go unnoticed in early years until they are confronted with more abstract tasks. Children in the second group demonstrated scores greater than the average in calculation and problem solving, and average reading comprehension.

Some of the aforementioned studies conducted with children older than 7 years old distinguished specific skill groups within the mathematical competence, such as applied problems, calculation, or problem solving. However, they did not provide a detailed analysis of specific domains associated with different types of mathematical thinking, namely informal and formal knowledge. According to Ginsburg and Baroody (2003), these ways of thinking are determined by the need (formal) or not (informal) to use mathematical symbols to solve the corresponding task. Although the informal mathematical knowledge has limitations in developing mathematical proficiency, researchers agree that the informal skills of preschoolers strongly predict subsequent mathematical performance (e.g., Jordan et al., 2009; Kilday & Kinzie, 2009). Several studies even suggested that early mathematical competence can predict not only later mathematical development but also future reading and science achievement (e.g., Claessens & Engel, 2013; Duncan et al. 2007). According to ten Braak et al. (2022), executive function appears to play a crucial role in this association, meaning that high early mathematical competence may promote the development of executive function skills, which in turn impact future academic achievement. In general, executive functioning is an important factor in the development of mathematical skills (Cragg & Gilmore, 2014). Under this perspective, students with ASD may experience additional difficulties in this transmission due to the executive function impairments that they often present (Demetriou et al., 2019; St. John et al., 2018).

On the assumption that early detection of non-typical mathematical development can help to prevent subsequent difficulties, several tests have been developed to assess basic mathematical competence (e.g., Núñez & Pascual, 2011). In particular, the *Test of Early Mathematical Ability* (3rd edition; TEMA-3, Ginsburg & Baroody, 2003) is a valuable tool for identifying such difficulties in children aged 3 to 8 years and 11 months old. The TEMA-3 assesses different aspects of mathematical competence, including both informal and formal tasks, which allows specialists to determine specific strengths and weaknesses in a student's proficiency. In the present study, the Spanish version of the TEMA-3 (Ginsburg et al., 2007) was used to assess the mathematical skills of 17 students diagnosed with ADS without intellectual disability. A comparison group was also recruited, consisting of students without ASD matched one-to-one by sex and schools (grade and classroom) with those in the ASD group. Our aim is to determine whether the recruited students with ASD experienced more difficulties in learning mathematics compared to their non-ASD peers. The research questions that guide our study are as follows:

1) Are there significant differences in mathematical competence between students in the ASD and the non-ASD groups?
2) Do students from the ASD group show different relative performance as they age?

3) In which type of mathematical knowledge (informal or formal, and within their respective subcategories) do students with ASD experience more difficulties?

We also discuss the potential implications of our findings for the design of effective mathematics teaching interventions for students with ASD.

Method

We employ a hybrid methodological strategy that incorporates both quantitative and qualitative aspects. The quantitative approach is used to determine the significance of the observed differences between the students with and without ASD, as well as to identify those tasks that may be more challenging for students with ASD. Subsequently, a qualitative analysis of the results is conducted to explore potential educational implications.

Data-collection Instrument

The TEMA-3 is a standardised test designed to assess the mathematical competence of children between the ages of 3 and 8 years and 11 months old. However, the authors suggested that the test can also be appropriate for older students who may be experiencing learning difficulties. The test has a reported internal consistency of 0.92 for the neurotypical populations, as measured by Cronbach's alpha (Ginsburg et al., 2007).

The TEMA-3 includes a total of 72 items that are divided into two major domains: informal thinking (41 items) and formal thinking (31 items). These domains are further divided into four specific categories each. The informal thinking domain includes items related to numbering (23 items), number comparison (six items), calculation (eight items) and concepts (four items). The formal thinking domain includes items related to numeral literacy (eight items), number facts (nine items), calculation (nine items) and concepts (five items).

The test yields a direct score that represents the number of correct items, with the floor and ceiling levels predetermined. The floor is determined when the student solves correctly five items consecutively. For the purpose of calculating the direct score, all items below this floor are deemed correct, regardless of whether the student has answered them correctly or not. The ceiling is reached when the student fails to solve five items in a row, marking the end of the test. However, regardless of which items are considered correct to compute the direct score of the test, it could also be essential to examine which specific tasks the students struggle with to understand their individual profiles. In some cases, the results may be reported in terms of mathematical age, which is estimated based on the direct score (Ginsburg & Baroody, 2003).

Although the TEMA-3 was originally designed to evaluate mathematical skills in typically developing children, it has been found to be a useful tool to assess the numerical skills and identify learning difficulties in students with special educational needs, as noted by Ginsburg et al. (2007). Several studies have employed the TEMA-3 to measure the mathematical competence of students with special educational needs (e.g., Bruno et al., 2021; Dueker & Day, 2022; Green et al., 2018; Henner et al., 2021; Vostanis et al., 2020). In particular, the test has proved to be useful to appraise the mathematical performance of students with ASD (e.g., Apanasionok et al., 2021; Goñi-Cervera et al., 2023; Ingelin et al., 2021; Root et al., 2020; Tzanakaki et al., 2014). The test has been typically used as a pre- and post-test in impact assessment of teaching methodologies, but it has also been used to comparatively assess the mathematical competence of different populations, such as students with intellectual disability (Núñez & Lozano, 2003, 2005) or with attention deficit/hyperactivity disorder (González-Castro et al., 2014).

Participants

The present study was conducted with 17 students diagnosed with ASD who did not have any other psychiatric comorbidity and had an intelligence quotient (IQ) of 70 or higher. They were recruited between July 2019 and February 2021 from 12 different mainstream schools in the Spanish region of Cantabria. At the time of the research, they were enrolled in the first four grades of elementary education. The participants are part of a larger

TABLE 1

Characteristics of the ASD Group of Participants

Code	*Sex*	*Academic Year*	*Age (Years)*	*Mathematical Age (Years)*
S1	M	1°	6.25	7.08
S2	M	1°	6.25	6.67
S3	F	1°	6.33	6.58
S4	M	1°	6.50	5.50
S5	M	1°	6.67	5.50
S6	M	2°	6.75	7.00
S7	M	3°	8.33	7.08
S8	F	3°	8.42	6.92
S9	M	3°	8.50	7.08
S10	M	4°	8.75	8.17
S11	M	4°	8.75	7.92
S12	M	4°	8.83	6.75
S13	M	4°	9.25	6.33
S14	M	4°	9.25	6.83
S15	M	4°	9.50	9.00
S16	M	4°	9.58	7.00
S17	M	4°	10.83	7.75

TABLE 2

Characteristics of the Students in the Non-ASD Group

Code	*Sex*	*Academic Year*	*Age (Years)*	*Mathematical Age (Years)*
C1	M	1°	6.67	8.17
C2	M	1°	6.25	6.83
C3	F	1°	6.33	6.50
C4	M	1°	6.42	6.50
C5	M	1°	6.58	7.00
C6	M	2°	7.67	6.67
C7	M	3°	8.33	8.17
C8	F	3°	8.58	7.42
C9	M	3°	8.67	9.00
C10	M	4°	9.58	9.00
C11	M	4°	9.58	8.00
C12	M	4°	9.50	9.00
C13	M	4°	9.00	9.00
C14	M	4°	9.33	9.00
C15	M	4°	9.25	9.00
C16	M	4°	9.00	9.00
C17	M	4°	9.83	9.00

sample collected for a research project funded by the Spanish government. In this frame, a study carried out by Polo-Blanco et al. (2024) assessed the problem-solving abilities of students with ASD and examined the correlation between these skills and cognitive abilities. To accomplish this, various assessment sessions were conducted to measure both mathematical and cognitive variables. In the present study, we focus on the results yielded by the TEMA-3, which was administered during one of these sessions, for a portion of the sample.

Table 1 displays the characteristics of the 17 participants in this study. To ensure confidentiality, they were given codes in increasing order of age. The variables included in the table are: sex, academic year, chronological age, and mathematical age as measured by the TEMA-3 (Ginsburg & Baroody, 2003). As mentioned before, the TEMA-3 scores a maximum mathematical age of 8 years and 11 months old, but for most students with mathematical difficulties, the score is not expected to be saturated. In fact, this is the case of all participants except S15, who exhibited a mathematical age similar to his chronological age. The average age of the participants was 8.16 years old, with a standard deviation of 1.42 years. Two participants in the study were female (11.8%).

Additionally, we included a comparison group (referred to as "non-ASD") consisting of children without a diagnosis of ASD. To create this group, we selected students who were matched one-to-one with those in the group with ASD by sex and school (grade and classroom). Table 2 displays the characteristics of the students in the non-ASD group. In this case, they are listed correspondingly, according to the order defined in Table 1 (such that Si and Ci are paired students even though they might not be exactly the same age). The non-ASD group had an average age of 8.27 years, with a standard deviation of 1.32 years.

Results

To differentiate between potential early differences and late effects, we compared the scores of students in the ASD and non-ASD groups in two different age groups. To make this distinction, we chose to group the students based on their academic year, since the students in the non-ADS group were selected from the same classrooms as the students with ASD, and thus may not have been exactly the

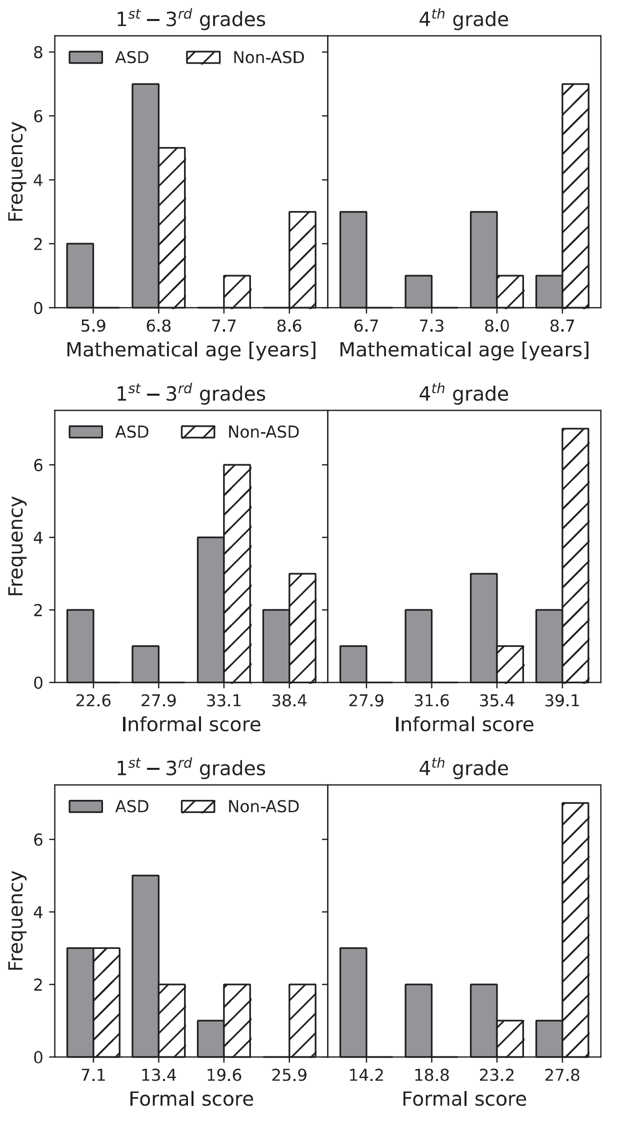

Figure 1. Distribution of Results from the TEMA-3, Including Total Scores, as well as Scores for the Informal and Formal Components.

same age. We created a first age group comprising first, second and third grade students (nine students in each group, both ASD and non-ASD), and a second age group comprising eight students per group in the fourth year of elementary school. Eventually, this split corresponded to participants below and above 8.7 years of age in our sample.

In addition to ensuring a similar number of children in each age group, we chose to split the students in this way for another reason. We wanted to separate the fourth graders from the others because their scores in the non-ASD group were predictably affected by saturation effects. As shown in Table 2 and the first panel of Figure 1, all but one of the students in the non-ASD group obtained a mathematical age of 9 years, which is the highest score possible on the test. Note that although the TEMA-3 is designed to assess mathematical competence in typically developing children under 9 years of age, this tool

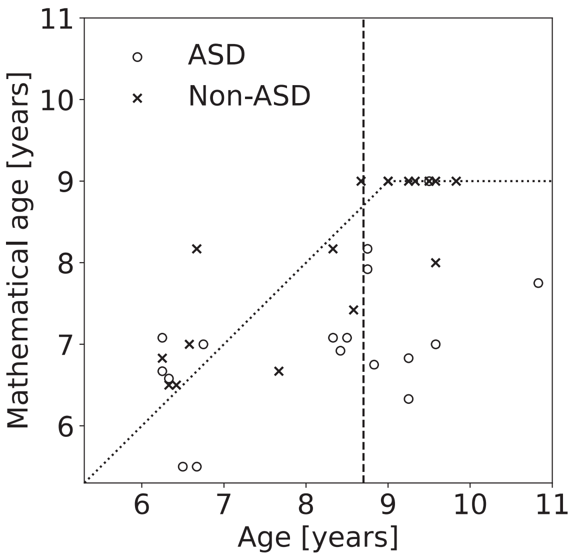

Figure 2. Comparison between Chronological and Mathematical Age of the Participants.

can still be sensitive to assessing older students with learning difficulties, as mentioned in the methodology section.

Figure 1 shows the frequency of values for mathematical age, informal and formal total scores for each age group. We binned the results into four groups for better visualisation, and the x-axis ticks represent the centres of the different bins. Note that the bin centres are not necessarily integers since the score is considered a continuous measure for visualisation purposes. The bars from the ASD and non-ASD groups are paired, so the presence of a single bar indicates that no values within the corresponding bin are obtained by the students in the other group. For example, no students with ASD in the first to third grades obtained mathematical ages belonging to the two highest bins, while only students with ASD in fourth grade obtained mathematical ages belonging to the two lowest bins.

Since the mathematical age is a function of the total direct score yielded by the test, it is worth investigating whether the informal and formal components contribute differently to group differences. The second and third panels of Figure 1 show the results for the informal and formal direct scores, respectively. Among first to third graders, the ASD group generally scored lower on the informal components, whereas both ASD and non-ASD groups scored lower on formal components. However, in this latter case, high scores were not associated with students with ASD. Among fourth graders, although the students with ASD obtained varied scores, several ones fell in the lowest range on both informal and formal mathematical knowledge, whereas the students in the non-ASD group frequently obtained the expected saturated score.

Figure 2 provides insight into the distribution of mathematical age as measured by the TEMA-3 relative to biological age. The dashed vertical line separates the two age groups at 8.7 years, while the dotted line represents the expected trend. The shaded region indicates that the TEMA-3 is not sensitive to estimating mathematical ages within that range. For the first to third grade group, five of the nine students with ASD had a mathematical age lower than expected, with relative shifts of 15.4%, 17.5%, 15.0%, 17.8% and 16.7% for S4, S5, S7, S8 and S9, respectively. In comparison, only three students in the non-ASD group scored lower than expected, with relative shifts of 13.0%, 1.9% and 13.5%, for C6, C7 and C8, respectively. Among the students who scored above the expected value, C1 had the greatest relative shift of 22.5%, while the top score in the ASD group was from S1, with a

TABLE 3

P-Values Obtained from a One-Tailed Mann-Whitney U Test Applied to Results from the TEMA-3: Total, Informal and Formal Scores

	1st–3nd (*9 Students*)	*4th* (*8 Students*)
Total direct score	0.144	0.007**
Informal direct score	0.058	0.011*
Formal direct score	0.154	0.003**

* <0.05. ** <0.01.

relative shift of 13.3%. Interestingly, both students belonged to the same classroom and school. For the fourth-grade group, all but one student with ASD obtained scores lower than the expected level, with age relative shifts up to 31.5% (as in the case of S13). By contrast, only one of the students in the non-ASD group (C11) scored lower than expected, with a relative shift of 16.5%.

To determine if the observed differences between the ASD and non-ASD groups are statistically significant, we conducted a hypothesis test. Since our results are not normally distributed, we used a one-tailed Mann-Whitney U test to investigate whether the scores obtained by students in the ASD group were similar to those obtained by the non-ASD group (H_0) or, alternatively, whether the former were typically lower than the latter (H_1). The corresponding *p*-values are shown in Table 3.

Note that while we present the results for the direct score from the TEMA-3 because we consider it a more empirical variable, similar results are obtained using the mathematical age, which is a function of the former. Regarding the first to third graders, the difference between the ADS and the non-ADS groups was not significant when considering a standard level of significance (0.05). However, in the case of the fourth graders, we were able to reject the null hypothesis. This means that the scores obtained by the fourth-grade students with ASD were more likely to be lower, which can be visually appreciated in the right panels of Figure 1 and the right section of Figure 2. Similar results were obtained for direct total scores of both informal and formal components.

Informal Knowledge. An analogous analysis was performed using the scores obtained for the informal-knowledge categories of the TEMA-3. While the TEMA-3 has a total of 23 items under the numbering category, only six, eight and four items are considered for number comparison, calculation and concepts, respectively. Figure 3 shows the direct scores obtained for each category by the students in different groups. As in the previous analysis, the scores are grouped into equally-spaced bins. Due to the low variability of scores in some categories, such as number comparisons or concepts, we used a smaller number of bins.

Considering the first to third graders, all the participant in the non-ASD group scored within the bin with the highest values for numbering and number comparisons, while the ASD group scores were spread out across the remaining bins. Both groups scored similarly in calculation, although two students within the ASD group scored in the lower range, and two students within the non-ASD group scored in the higher range. Both groups had varying scores in concepts. Among fourth graders, higher scores were observed in numeracy for the non-ASD group and, apparently, also in calculation and concepts.

To assess the statistical significance of these differences, Table 4 collects the *p*-vales computed from a one tailed Mann-Whitney U test for the different scores of informal categories. Considering a standard level of significance of 0.05, we were able to reject the null hypothesis in the all cases except for concepts within the first to third graders and numbering within the fourth graders. This indicates that, in most cases, students in the ASD group were more likely to answer fewer questions correctly.

Formal Knowledge. Figure 4 shows the results for formal-knowledge categories. Each category is visualised using four equally-spaced bins, except for numeral literacy for fourth graders, in which only two different results were obtained (scores of 7 and 8).

Considering the first to third graders, scores for both the ASD and non-ASD groups were spread across the possible range of values for number literacy and number facts. For

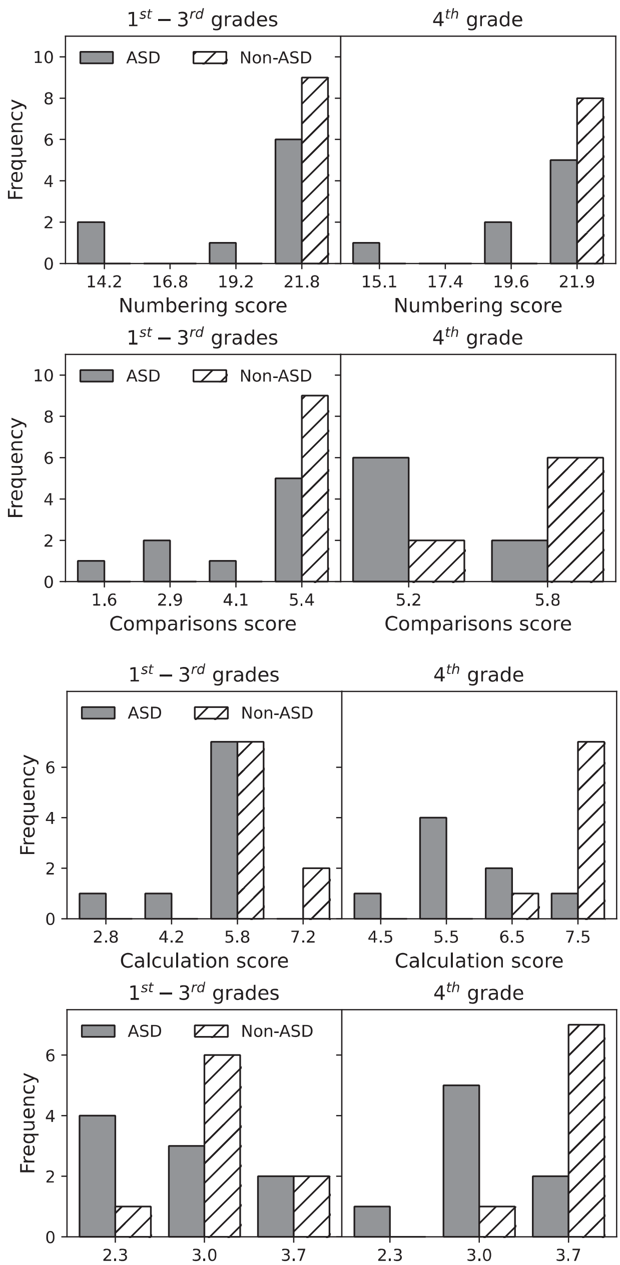

Figure 3. Distribution of Results from the TEMA-3: Scores from the Informal-Knowledge Categories.

formal calculation and concepts categories, the scores from students with ASD appeared to be within the lower bins, while those from the non-ASD group were spread across the range, as in the rest of categories. It is important to note that the TEMA-3 has few items associated with formal knowledge for ages under 7.5 years old, especially for the number facts, calculation, and concepts categories. Thus, many students within this age

TABLE 4

P-Values Obtained from a One-Tailed Mann-Whitney U Test Applied to Results from the TEMA-3: Scores from the Informal-Knowledge Categories

	1st–3nd *(9 Students)*	*4th* *(8 Students)*
Numbering	0.029*	0.101
Number comparisons	0.005**	0.030*
Calculation	0.030*	0.004**
Concepts	0.168	0.008**

*<0.05. ** <0.01.

group might be too young to acquire this knowledge, regardless of their ASD diagnosis.

However, for fourth graders and all formal categories, the scores obtained by the students with ASD were more likely to be lower than those obtained by the students in the non-ASD group. Table 5 presents the *p*-values computed from a one tailed Mann-Whitney U test for the different scores of formal categories. Taking into account a standard level of significance of 0.05, the differences within the first to third graders were not statistically significant, except for the concepts category. However, we were able to reject the null hypothesis in all cases for the fourth-grade students.

Difficulties with Specific Items in the ASD Group. Setting the target of improving mathematical teaching interventions for students with ASD, it could be beneficial to identify the specific tasks where they struggle the most. In this regard, a qualitative analysis was conducted to explore the most challenging tasks for the students with ASD in our sample, which were selected in the categories that in the previous analysis presented *very* significant differences (p-value < 0.01) between the ASD and non-ADS groups.

For the first to third graders, the most significant differences between the ASD and non-ASD groups within the informal-knowledge categories were observed for number comparisons. Upon a detailed analysis of each task within this category, it was revealed that items 26 and 35 (I26 and I35, respectively) posed the most difficulties for the students with ASD. Both tasks require mental representation of the number line, with students being shown numbers between two others and asked to identify which number of the sides is closer to the one in the centre. One-digit numbers are considered in I26, while I35 is a two-digit version of the same task. Whereas all the students in the non-ADS groups solved both tasks correctly, only three students with ASD were able to solve I26, and only one of them could do so with I35. Within the formal-knowledge categories, no very significant differences (p-value < 0.01) were observed between the ASD and non-ASD groups for first to third graders.

When considering the fourth graders, very significant differences were found within the informal-knowledge calculation and concepts categories. Upon analysing the calculation category in detail, it was revealed that I62, I65 and I72 posed difficulties for students with ASD. These tasks assess mental addition (I62) and subtraction (one-digit version in I65, and two-digit version in I72) through three verbal problems. While all the students in the non-ADS group answered I62 correctly, only two students with ASD managed to do so. Additionally, only two students with ASD correctly solved I65 (one of them also correctly solved I62, but the other did not do so), compared to seven students in the non-ASD group. The two-digit mental subtraction was more challenging as only a half of the students in the non-ASD group solved correctly the task in I72. In comparison, only one student with ASD was able to solved it well. In the informal concept category, I46 seemed to pose difficulties for the students with ASD. This task assesses the part-whole concept through four verbal problems. Only one student with ADS correctly solved I46, compared to six students in the non-ADS group.

Within the formal categories, a very significant difference was observed between ASD and non-ADS groups of fourth graders for calculation, highlighting difficulties in I54, I58, I59, I63, I69 and I70. I54 presents several word problems to assess mental additions and subtractions in the form of *tens* ± *10*, while I58 requires the student to carry out sums with three-digit numbers. I59 and I63 present several word problems to work with sums and subtractions, respectively, with multiples of ten. Finally, I69 and I70 evaluate subtractions of three-digit numbers with carrying.

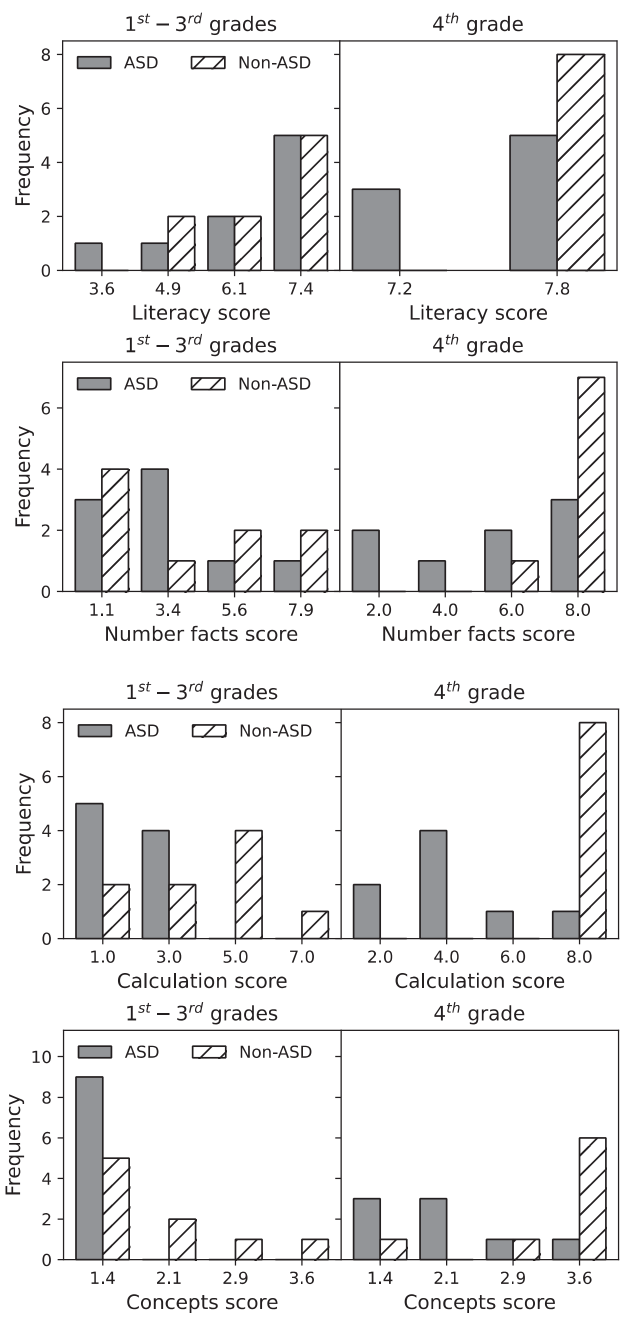

Figure 4. Distribution of Results from the TEMA-3: Scores from the Formal-Knowledge Categories.

Discussion

The present study aimed to evaluate the mathematical competence of 17 students with ASD recruited from first through fourth grades in 12 different schools in the Spanish region of Cantabria. The TEMA-3 (Ginsburg et al., 2007) scores of these students were compared with those of 17 non-ASD students who were matched one-to-one by sex and

TABLE 5

P-Values Obtained from a One-Tailed Mann-Whitney U Test Applied to Results from the TEMA-3: Scores from the Formal-Knowledge Categories

	1st–3nd (9 Students)	*4th* (8 Students)
Numeral literacy	0.234	0.037*
Number facts	0.211	0.029*
Calculation	0.053	0.002**
Concepts	0.017*	0.011*

*<0.05. ** <0.01.

school (grade and classroom) of those of the former group. The results presented here expand our understanding of the mathematical achievement of students with ASD and identify possible difficulties related to concrete aspects of informal and formal mathematical knowledge.

Specifically, the results indicate that students with ASD in this study exhibited more difficulties in mathematics than their peers without ASD. This finding is consistent with previous studies reporting that students diagnosed with ASD without intellectual disability generally experience more challenges in mathematics than their peers without ASD (e.g., Chen et al., 2019; Mayes & Calhoun, 2006; Polo-Blanco et al., 2022).

Additionally, as evidenced by studies with children with ASD of varying ages (Bullen et al., 2022; Chen et al, 2019; Titeca et al., 2014; Wei et al., 2015), our results suggest that the differences in mathematical performance between the ASD and non-ASD groups become statistically significant in higher grades. While previous studies (Titeca et al., 2014) did not identify significant differences in mathematical performance between preschoolers with and without ASD, our findings indicate notable distinctions in the first few years of elementary school, particularly for informal knowledge. Since informal knowledge lays the groundwork for future formal knowledge (Ginsburg & Baroody, 2003), early struggles with informal tasks like the ones that we observed in our study among first to third grade students with ASD may be contributing to more pronounced deficits in formal knowledge among fourth graders. Other researchers showed that many students with ASD maintain satisfactory mathematics performance during the early elementary grades, but encounter greater difficulties in later grades as the subject matter becomes more abstract and cognitively demanding (Barnett & Cleary, 2015; Whitby & Mancil, 2009). In light of our results, it would be important to conduct further research to investigate potential differences in informal knowledge among larger samples of pre-schoolers and early elementary school children, and to identify which of these aspects could serve as predictors of later performance.

The students with ASD who participated in the present study experienced difficulties in both informal and formal mathematical categories. In the case of informal mathematical knowledge, the students with ASD showed difficulties at all ages. For first to third graders, difficulties were especially present in items of number comparisons. Specifically, they struggled with items related to mental representation of the number line. These difficulties could evidence that some of the students with ASD had not yet developed a mental image of the number line, which in turn could be related to challenges with abstract reasoning typically attributed to people with ASD (Minshew et al., 2002; Ozonoff & Schetter, 2007). Alternatively, the identified difficulties may reflect struggles with key mathematical concepts, such as comparison terms like “plus”, “minus”, “near to”, and “far from”, which have been previously observed in other studies on mathematical learning with students with ASD (Polo-Blanco & González, 2021; Polo-Blanco et al., 2019). They may also be related to language comprehension difficulties common in people with ASD (American Psychiatric Association, 2013). For the fourth graders, informal-knowledge categories of calculation and concepts posed significant challenges, especially in items with strong verbal components. Again, language difficulties typically observed in people with ASD may be a contributing factor to this, as they have been linked to challenges in solving verbal mathematical tasks (Alderson-Day, 2014; Polo-Blanco et al., 2022). Formal mathematical knowledge difficulties were not evident until fourth grade, when they were severely present in all categories except for number literacy. Students with ASD had the most difficulty in calculation and concepts categories, particularly in items involving operations with carrying and strong verbal components.

Future work could be based on these findings to design targeted math learning supports for students with ASD. The results suggest that teachers should prioritize reinforcing informal skills from an early age, as this may facilitate the development of formal skills in later years. For example, in light of the difficulties observed in items of informal number comparisons, tasks could be carried out that incorporate visual support to aid in the understanding of key comparison words such as "greater" and "smaller". Polo-Blanco and González (2021) successfully utilized similar supports, additionally incorporating a progression of the level of abstraction of quantities from concrete to abstract, which considerably reduced numerical comparison errors in three students with learning difficulties, one of whom was diagnosed with ASD. Moreover, considering the difficulties evidenced in informal items with verbal statement, adaptations could be made that incorporate supports with pictograms, as well as self-instruction lists with visual aids, to guide students in task resolution. Similar methodologies have been successfully carried out with students with ASD in the resolution of mathematical word problems (e.g., García-Moya et al., 2022), compensating for possible verbal difficulties (Mayes & Calhoun, 2006) as well as planning difficulties (Ozonoff & Schetter, 2007) characteristic of the disorder.

The conclusions drawn from this analysis are primarily constrained by the small size of our sample. Specifically, we were unable to identify different achievement profiles as some of the aforementioned studies reported (Bullen et al., 2022; Chen et al., 2019; Wei et al., 2015). Furthermore, future research could provide further insight into these issues using a longitudinal approach and aid in the development of effective teaching interventions for students with ASD.

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