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Autism shapes social integration and reciprocity in elementary classrooms

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During childhood, schools are crucial environments for social interactions, making them ideal for evaluating the inclusion of students with special educational needs (SEN). In particular, autistic children often face challenges in peer relationships, yet the impact of autism on social dynamics in schools is not well understood. To address this issue, we examined social dynamics within elementary schools. We hypothesized that, compared to their non-autistic peers, autistic children occupy more peripheral positions in social networks and engage less in reciprocal relationships. To test these hypotheses, we introduced a novel ecological approach using experimental game theory to quantify social integration and reciprocity among autistic children. Social networks were constructed for each classroom based on the children's peer selections during a distributive game where they had to send tokens to their peers. Six elementary schools took part in this study. From these schools, 26 classrooms from first to fourth grade were included, comprising a total of 625 students aged 6 to 11. Among them, 464 were students without SEN, 143 were students with SEN excluding autism, and 18 were autistic students. Our analysis showed that autistic children and children with SEN were significantly less central and less involved in reciprocal peer relationships compared to children without SEN. Due to the small sample of autistic students, further research with greater statistical power is needed to clarify the specificity of the results. These findings highlight the need for support in promoting social inclusion while also emphasizing the importance of exploring the intersection of neurodevelopmental conditions and social dynamics.

Keywords Social networks, Autism spectrum disorder, Neurodevelopmental disorders, Inclusive education, Experimental game theory

Schools are a critical environment during childhood where all kinds of social interactions occur. Knowing how to live with others who are different is crucial for satisfactory social relationships[1]. From the perspective of individual development, evidence has shown that a variety of affective and cognitive processes can influence how children develop their social behaviors and integrate into peer groups. Certainly, the maturation of these processes is not homogeneous among children, as it is influenced not only by neurodevelopmental variables but also by family dynamics, local contexts, and cultural meanings[2]. From an inclusive perspective, studying social interactions in schools becomes relevant, considering that the educational context serves as a space for encounter and coexistence in diversity[3]. In this setting, some children who could face different learning barriers participate alongside their peers in formative activities[2,3]. Understanding how children with special educational needs (SEN) manage these social dynamics is crucial, especially considering neurodevelopmental conditions such as autism, which evidence has consistently shown to be associated with social difficulties and challenges in social interactions.

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From a multidimensional perspective, autism has been recognized as a neurodevelopmental variation characterized by distinct patterns of social communication, interaction, and behavior across contexts, often associated with varying support needs throughout the educational trajectory[4]. Along with these support needs, autism is also characterized by the presence of a focused and intense pattern of behaviors, interests, or activities[4,5]. These characteristics reflect divergent ways of experiencing and engaging with the social and sensory environment, which can influence how autistic children are perceived by others and how they navigate social settings.

From early in life, autistic children and those with an increased likelihood of being on the autism spectrum exhibit distinct patterns of attention to social stimuli[6–9]. Evidence has shown that challenges in understanding others' emotions and in the ability to comprehend the perceptions and experiences of others—known as theory of mind or mentalization—correlate with challenges in socio-adaptive and pragmatic communication, including differences in initiating communication and interpreting language coherence depending on the context[10–12]. These social and communicative skills are relevant to the educational process, as they play a key role within the school context. Rather than reflecting deficits, these features highlight alternative ways of engaging in social interactions, which can sometimes be misunderstood or misinterpreted by peers[13].

In this context, the educational setting is particularly challenging for all children, as it requires a range of social and communicative skills. Studies in non-autistic children show that challenges in social communication are linked to lower peer acceptance and higher risk of social exclusion[14]. In the case of autistic children, these demands intersect with their distinct ways of engaging in social interactions, shaping both their integration into peer groups and how they are perceived by others. Moreover, autistic children and adolescents are at an elevated risk of experiencing bullying victimization compared to non-autistic students and students with disabilities or neurodevelopmental conditions different from autism[15–18]. Behaviors such as making naive and embarrassing remarks, difficulties knowing how to cooperate in a team, and having involuntary face or body movements have been statistically associated with an increased likelihood of being victimized[15].

Previous findings using social network analysis have highlighted the challenges faced by autistic individuals in social contexts[19–21]. Evidence shows that autistic adolescents often experience poorer peer relationships, increased feelings of loneliness, and social isolation compared to their non-autistic peers[19]. In addition, studies have also shown that autistic students often occupy peripheral positions in classroom social structures and receive fewer friendship nominations[20,21]. These findings underscore the importance of understanding peer dynamics in inclusive contexts. Furthermore, this evidence stresses the importance of recognizing that mutual social engagement is inherently a two-way relationship. Challenging deficit-based views, the social challenges that arise stem from a reciprocal lack of understanding between autistic and non-autistic individuals, emphasizing the need to consider the relational dynamics at play and move toward mutual understanding and empowerment[13].

For the purposes of this study, we refer to three student groups: autistic students, students with SEN, and students without SEN. This classification allows us to examine how peer dynamics and social positioning may vary across different educational support contexts, while maintaining an inclusive perspective on individual differences. In this context, examining neurodevelopmental diversity among children can provide insights into how social interaction networks are shaped within school settings. Measuring social networks during childhood requires tailored instruments that ensure inclusivity and avoid stigmatizing children as "different" or "atypical"[22,23]. Considering this evidence, we tested two hypotheses: compared to children with and without SEN, autistic children (i) occupy more peripheral positions within social networks, reflecting a low degree of centrality, and (ii) engage less in reciprocal relationships, indicating diminished social reciprocity. We address these aspects by designing a game that is played on a user-friendly interface, which enables the identification of participants' revealed preferences regarding social interactions and thus elicits the collaborative social network within each classroom[24,25]. Our ecological computational game, based on experimental game theory, uncovers children's implicit social preferences. Unlike traditional self-report methods, our game requires students to actively choose partners and allocate resources within a controlled environment. By focusing on constrained resource distribution, it captures nuanced social dynamics and reciprocity in elementary classrooms, offering unique insights into social inclusion and a novel framework for understanding integration among children with diverse educational needs.

Based on the children's choices, social networks were constructed for each classroom and centrality and reciprocity measures were analyzed[26]. After analyzing centrality network measures, we found that autistic children received significantly fewer selections and preferences, and exhibited lower engagement in reciprocal relationships compared to their peers without SEN or with SEN. Given the small sample of autistic children, further research with greater statistical power is needed to clarify the specificity of the results, as discussed in more detail in the Discussion.

By analyzing the social dynamics and interactions of children with diverse neurodevelopmental trajectories, we aim to better understand the unique social challenges faced by autistic children in educational environments and to contribute to informing inclusive school coexistence policies.

Results
Language note
In this article, we have chosen to employ identity-first language when referring to autistic children. This choice reflects a growing recognition that autism is a fundamental aspect of identity for many within the autistic community. While acknowledging the historical use of person-first language, we aim to align with current trends and preferences within the community and to affirm autism as a valued form of neurodiversity[27–29].

The game of the stars

Based on experimental game theory[24,25], a computational distribution game was developed to construct students' social networks called the Game of the Stars. This game enables the identification of participants' revealed preferences regarding social interactions and thus elicits the collaborative social network within each classroom.

The game consists of four sequential stages. In the **Real Effort Task** stage, children earn 15 stars by popping moving bubbles, fostering engagement and a sense of ownership over the rewards. Then, in the **Classmate Selection** stage (Fig. 1a), they manually scroll through headshots of classmates to select 10 peers they wish to interact with. In the **Star Allocation** stage (Fig. 1b), children distribute their 15 earned stars among the selected classmates. Finally, in the **Peer Nominations** stage, children indicate which classmates they would like to hang out with, avoid, or consider friends (for details, see Methods).

Social network measures

To analyze student interactions within each classroom, we constructed networks in which students are represented as nodes linked based on their behavior in the game. Each network consists of two layers: The first, the player choice network, consists of non-weighted directed links derived from the Classmate Selection stage of the game. The second, the stars allocation network, includes weighted directed links representing the number of stars sent, derived from the Star Allocation stage of the game (Fig. 1c). From this network structure, we analyze two main components: students' positions in the network based on the centrality and their reciprocity behavior (for details, see Methods).

Game social network centralities

We first evaluated how well the social network centralities derived from our game reflect the students' declared social preferences. We analyzed the correlation between game-derived centrality measures and peer nominations across all students. A total of 625 children aged 6–11 years, from first to fourth grade, participated in the study, including 464 students without SEN, 143 students with SEN excluding autism, and 18 autistic students.

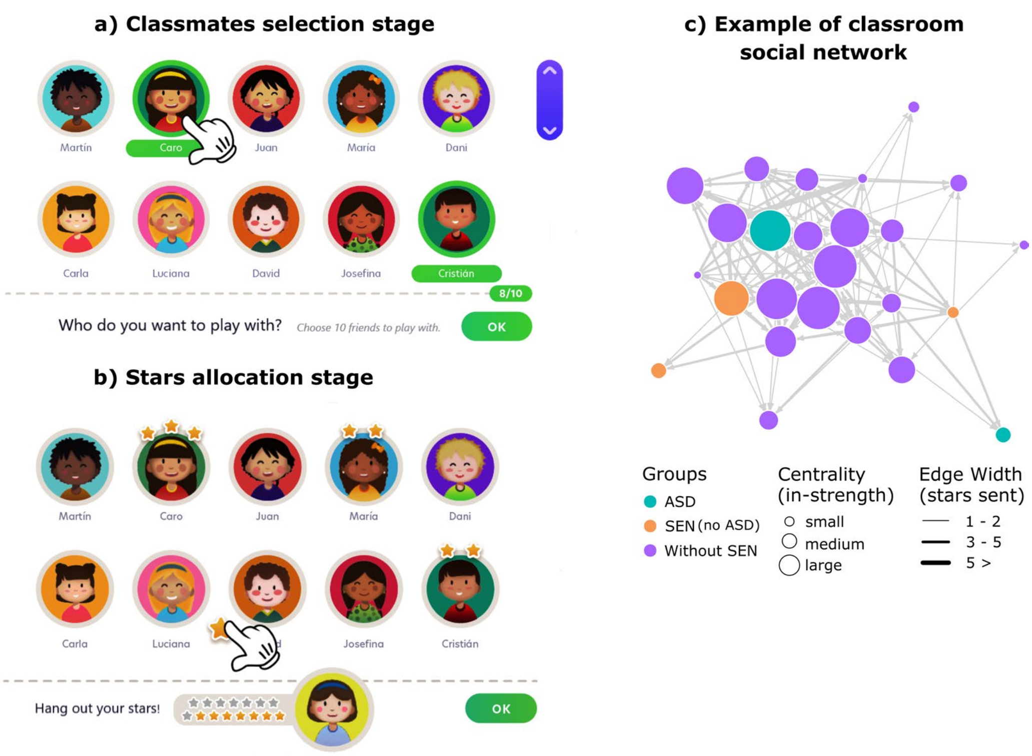

Fig. 1. The Game of the Stars Interface and Network. Left panel depict the (**a**) selection of classmates' stage, and (**b**) stars allocation stage. Avatars are used for illustrative purposes only. During gameplay, children had access to pictures of their classmates in order to ensure that the selection and preferences were correctly allocated. The Game of the Stars was developed in collaboration with Niebla Games and Invade Lab. Image reproductions are used with permissions from both companies. The game is not publicly available. The links to their official websites are provided solely as a source reference: https://www.nieblagames.com/ and https://invadelab.cl/. (**c**) Example of a 2nd-grade classroom social network. Each circle represents an individual student in the classroom. Purple circles depict children without SEN, while yellow circles represent children with SEN (excluding ASD). Green circles represent autistic children. The lines show the specific interaction between two students, with the thickness reflecting the number of stars received in that particular interaction. The size of each circle corresponds to the total number of stars received.

The results showed a positive association between the standardized choice in-degree (i.e., the number of times classmates chose them, see the Methods section), standardized stars in-strength (i.e., the number of stars they received from their classmates), and the child's willingness to hang out with and be friends with certain classmates (Supplementary Fig. S1 and Supplementary Table S1). Conversely, a negative correlation was observed between these centrality measures and students' reluctance to socialize with and befriend specific classmates (Supplementary Fig. S1).

These findings suggest an association between a student's social position within the peer group and their interpersonal behaviors and preferences, regardless of their student group (i.e., autistic students, students with SEN, or students without SEN).

Children with SEN and autistic children are less central

We analyzed centrality measures examining variations among student groups (for details, see Methods).

Our results showed that, compared to children without SEN, students with SEN consistently exhibited significantly lower centrality scores, specifically in their average in-degree centrality (Wilcoxon test, $p = 0.0025$) and in-strength centrality (Wilcoxon test, $p = 0.0026$).

Similarly, autistic children also showed significantly lower in-degree and in-strength measures than their peers without SEN (in-degree Wilcoxon test, $p = 0.004$; in-strength Wilcoxon test, $p = 0.0025$). Compared with children with SEN, autistic students showed a smaller magnitude of these differences, yet still significantly lower in the in-strength measure within the stars network (Wilcoxon test, $p = 0.035$). However, the differences in the choice network's in-degree measure were no longer significant ($p = 0.054$) (Fig. 2a). These patterns held across other centrality measures: PageRank (influence based on the importance of connections), Closeness (proximity to all peers in the network), and Betweenness (role as a bridge between disconnected classmates). The results remained robust for autistic children (Fig. 2b).

To further explore these associations, we quantified the relationship between children's network centrality and student group using linear regression models, while controlling for potential confounding variables (see Methods for details).

Our analysis showed (Table 1) that autistic students consistently exhibited significantly lower centrality, across both networks. Specifically, they received between 0.6 to 1.1 standard deviations less than the students without SEN. This difference remains robust after adjusting for factors potentially affecting social interactions, such as active participation in the game, class attendance, grades, grade level, and the specific classroom to which a student belongs (see Supplementary Table S7).

Regarding students with SEN, our findings indicated that the estimated coefficients were consistently negative, suggesting lower centrality compared to their peers without SEN. However, these differences ceased to be statistically significant when controlling for attendance and grades. This suggests that the heterogeneity among students with SEN may influence their social positions within the classroom.

Models 1 and 2 in Table 1 display the estimated models for the number of times a student was chosen by their classmates (in-degree), indicating a significant association between having a condition of SEN and students' centrality. Specifically, students with SEN were chosen 1.2 fewer times on average (Model 1, $p < 0.01$). The effect was more pronounced for autistic students, who were chosen 2.8 fewer times (Model 1, $p < 0.01$) compared to peers without SEN. The negative impact of autism on social standing becomes even larger in Model 2, where autistic students were chosen 4.7 fewer times ($p < 0.01$) after adding controls for grades and attendance. Standardized coefficients are reported for all models, allowing for comparison of effect sizes across variables.

Models 3 and 4 present the estimated coefficients for the total number of stars received by a student from their classmates (in-strength). Similar to the in-degree centrality results, we observed that students with SEN received 2.1 fewer stars (Model 3, $p < 0.05$), and autistic students received 5.2 fewer stars (Model 3, $p < 0.01$) in average compared to those without SEN. This pattern remains consistent after adding controls for grades and attendance.

In order to address the limitations in causal interpretation of the social dynamics among the groups, we implemented a null model filtering approach. This method distinguishes meaningful interaction patterns by identifying and removing exchanges that can be attributed to random chance, while preserving each participant's total number of choices (out-degree) and the number of interactions initiated (out-strength) (for details, see Methods). Importantly, the results of the filtered null model consistently replicated the previously described centrality patterns (Supplementary Table S4 and Supplementary Fig. S2).

In summary, our statistical models robustly demonstrated that autistic students were significantly less central among their classmates. Furthermore, we found that the overall average negative association was primarily driven by larger negative coefficients for autism compared to smaller negative coefficients for other SEN categories. These associations were consistent across various models and control conditions.

Stars distribution profiles

We questioned whether the observed differences in in-strength coefficients among groups could be associated with a tailored star distribution profile for certain groups of children. To investigate this, we compared the concentration of stars allocated in student groups.

Using the Gini coefficient[30], a measure of inequality in a distribution, we examined how concentrated or dispersed the star distributions were for each group. In the context of our game, a higher Gini coefficient indicates a greater concentration of stars, suggesting a preference for closer, more selective relationships. Conversely, a lower Gini coefficient reflects a more equitable distribution, indicating an effort to maintain fair relationships with a broader group.

We found that overall, children tended to privilege more equitable distributions of stars, with an average Gini coefficient of 0.33, indicating high equity. While there was some variation within the different groups, we did

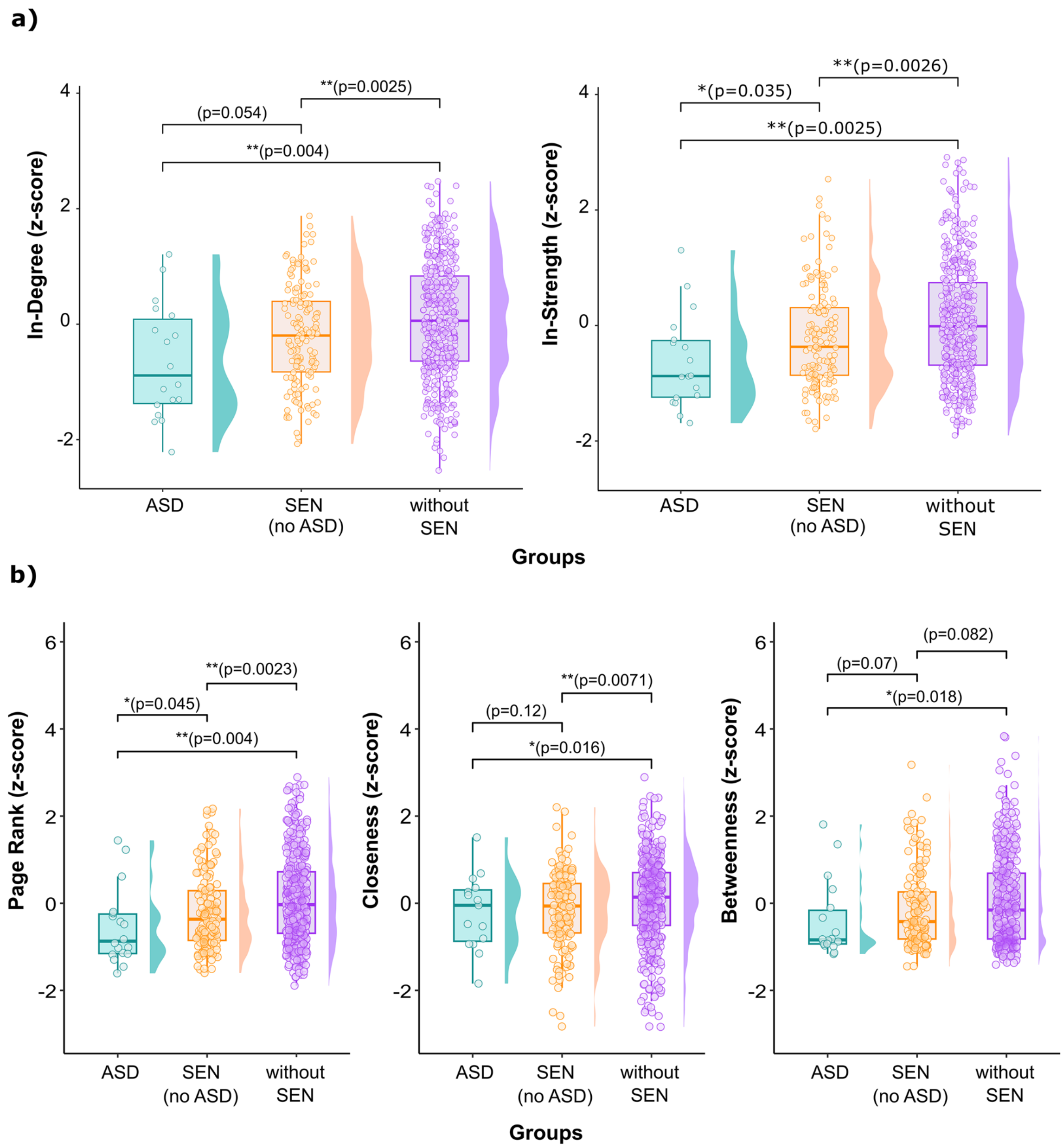

Fig. 2. Centrality measures among groups of students. (**a**) Upper panel shows the standardized in-degree and in-strength centrality measures. Left plot displays the selections received for the students. Right plot illustrates the stars that children received from their classmates for each group of students. (**b**) Lower panel shows the standardized Page Rank, Closeness and Betweenness measures in the stars networks for each group of children. In both panels, each circle represents one student. Green circles represent autistic children, orange circles represent the group of children with SEN excluding autism, and purple circles represent the group of children without SEN. We show pairwise Wilcoxon test p-values results. Abbreviations: ASD = Autism Spectrum Disorder, SEN = Special Educational Needs. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

not find any significant differences in the distribution patterns among the groups of children (Supplementary Fig. S3). This suggests that children adopted similar strategies in distributing their stars, favoring a balanced approach to maintaining social relationships.

Children with SEN and autistic children participated in fewer reciprocal exchanges

To comprehensively assess social dynamics among different groups of children, we estimated reciprocal measures reflecting their engagement in bidirectional relationships with their peers. To assess mutual preferences, only active players—both the chooser and the chosen—were included, reducing the sample to 530 students. This analysis revealed that autistic children engaged significantly less in reciprocal relationships compared to both their peers with SEN ($\chi^2(1) = 10.78$, p = 0.001), and their peers without SEN ($\chi^2(1) = 14.87$, $p = 0.00012$) (Supplementary Table S2).

Variable	Estimate	SE	95% CI		Estimate Std	Std. est.95% CI		*P*	R^2	Adj. R^2	N
			LL	UL		LL	UL				
Model 1—Dependent variable: In-degree (times chosen)									0.162	0.123	625
SEN (excluding ASD)	− 1.171**	0.407	− 2.009	− 0.333	− 0.293	− 0.503	− 0.084	0.008			
ASD	− 2.827**	0.998	− 4.883	− 0.77	− 0.708	− 1.223	− 0.193	0.009			
Active player	2.409***	0.490	1.4	3.419	0.604	0.351	0.857	< 0.001			
Model 2—Dependent variable: In-degree (times chosen)									0.233	0.192	455
SEN (excluding ASD)	− 0.782	0.554	− 1.946	0.381	− 0.196	− 0.488	0.096	0.175			
ASD	− 4.699**	1.393	− 7.626	− 1.772	− 1.177	− 1.911	− 0.444	0.003			
Active player	1.507	0.825	− 0.226	3.239	0.378	− 0.057	0.812	0.084			
Attendance	0.017	0.014	− 0.011	0.046	0.004	− 0.003	0.011	0.224			
Grades (GPA)	1.696**	0.443	0.765	2.626	0.425	0.192	0.658	0.001			
Model 3—Dependent variable: In-strength (received stars)									0.117	0.076	625
SEN (excluding ASD)	− 2.063*	0.804	− 3.72	− 0.407	− 0.269	− 0.485	− 0.053	0.017			
ASD	− 5.21**	1.697	− 8.705	− 1.716	− 0.679	− 1.135	− 0.224	0.005			
Active player	4.225***	0.846	2.482	5.967	0.551	0.324	0.778	< 0.001			
Model 4—Dependent variable: In-strength (received stars)									0.19	0.147	455
SEN (excluding ASD)	− 1.691	1.056	− 3.91	0.527	− 0.220	− 0.510	0.069	0.127			
ASD	− 8.982***	1.982	− 13.145	− 4.819	− 1.171	− 1.714	− 0.628	< 0.001			
Active player	1.806	1.541	− 1.432	5.044	0.235	− 0.187	0.658	0.257			
Attendance	0.032	0.027	− 0.025	0.089	0.004	− 0.003	0.012	0.258			
Grades (GPA)	3.293***	0.739	1.741	4.845	0.429	0.227	0.632	< 0.001			

Table 1. Linear regression models for centrality network measures. Four linear regression models examine the relationship between student characteristics and peer recognition in the classroom. Models 1 and 2 use in-degree (i.e., the number of times a student was chosen by peers) as the dependent variable, while Models 3 and 4 use in-strength (i.e., the total number of stars received from peers). Models 1 and 3 include binary indicators for SEN (excluding ASD), autistic students (ASD), and active participation in the game. Models 2 and 4 additionally control for attendance (as a percentage) and grade point average (GPA) on a 1–7 scale. All models include classroom fixed effects and cluster-robust standard errors at the classroom level. Standardized coefficients (Estimate Std.) are reported based on standardized dependent variables. Attendance and grade data were available for 455 of the 625 students. CI = Confidence interval; LL = Lower limit; UL = Upper limit; SE = Standard error *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

As with the centrality measures, we implemented fixed-effects linear regression models to quantify the association between children's reciprocated choice scores and their group (Table 2). Specifically, this score reflects the average proportion of mutual reciprocated choices or star allocations relative to what the student sent to their peers. We controlled for participants' overall attendance and school grades and included classroom fixed effects (see Methods for details).

Statistical models robustly showed that autistic students engaged in fewer reciprocal exchanges compared to students without SEN, considering both their peers' choices and their star allocations (Table 2). Although students with SEN also engaged in fewer reciprocal exchanges compared to students without SEN, this effect was smaller in magnitude and less robust than for autistic children. This statistical trend persisted when analyzing reciprocity across all interactions in both the choice and stars allocation networks, meaning the total number of choices and stars a student interacts with, including both those sent and received (Supplementary Table S3).

To further investigate whether the observed tendency of fewer reciprocal choices in the group of students with SEN, and especially autistic students, could be associated with a specific pattern of choices either from the sender, the receiver, or both, we conducted a dyadic-level analysis. We focused on determining whether the likelihood of a reciprocal choice was associated with the student group (Table 3).

First, we examined the likelihood of reciprocated choices between pairs of students. We found that pairs of students in which the sender did not have a SEN condition, and the receiver did have a SEN condition were 6% less likely to reciprocate choices compared to pairs of students in which the receiver did not have a SEN condition (Model 1, $p < 0.001$). For pairs of children involving autistic receivers, the likelihood to reciprocate choices decreased further by 17% (Model 1, $p < 0.001$).

We then explored mutual non-selection, a distinct aspect of reciprocity in which neither student chooses the other. The results showed that when the sender was a student without SEN and the receiver was a student with SEN there was a 5% higher probability of mutual non-selection occurring (Model 4, $p < 0.001$). Moreover, when the receiver was an autistic student, the likelihood increased by 11%, compared to pairs of students without SEN (Model 4, $p < 0.01$).

Interestingly, these trends do not hold statistically when both the sender and receiver are children with a SEN condition or are autistic children (Models 3, 5, and 6). Furthermore, the statistical trend reverses when the receiver and the sender are both autistic children (Model 6). Nevertheless, this result should be interpreted with

Variable	Estimate (Std.)	SE	95% CI LL	UL	*P*	R^2	Adj. R^2	N
Model 1- Dependent Variable: Reciprocated Choice Score (z-score)						0.227	0.186	530
SEN (excluding ASD)	− 0.276**	0.080	− 0.439	− 0.111	0.002			
ASD	− 1.082***	0.258	− 1.613	− 0.552	< 0.001			
Model 2—Dependent Variable: Reciprocated Choice Score (z-score)						0.237	0.193	409
SEN (excluding ASD)	− 0.173	0.101	− 0.385	0.039	0.104			
ASD	− 1.562***	0.257	− 2.102	− 1.022	< 0.001			
Attendance	0.009	0.004	0.000	0.019	0.058			
Grades (GPA)	0.377***	0.088	0.193	0.562	< 0.001			
Model 3—Dependent Variable: Reciprocated Stars Score (z-score)						0.191	0.148	530
SEN (excluding ASD)	− 0.258**	0.085	− 0.434	− 0.083	0.006			
ASD	− 0.724*	0.319	− 1.382	− 0.066	0.032			
Model 4—Dependent Variable: Reciprocated Stars Score (z-score)						0.224	0.180	409
SEN (excluding ASD)	− 0.193	0.098	− 0.399	0.012	0.063			
ASD	− 1.302***	0.190	− 1.700	− 0.904	< 0.001			
Attendance	0.010*	0.004	0.002	0.018	0.014			
Grades (GPA)	0.258**	0.088	0.072	0.443	0.009			

Table 2. Linear regression models for the ratio of standardized reciprocated choices and stars. Four linear regression models examine the relationship between student characteristics and measures of reciprocated peer interaction at the individual level. Models 1 and 2 use the standardized reciprocated choice score as the dependent variable, defined as the proportion of a mutual selections a student received from classmates. Models 3 and 4 use the standardized reciprocated stars score (z-score), which represents the total number of stars a student received in mutual interactions, relative to the number of stars they sent to peers. Models 1 and 3 include binary indicators for students with SEN (excluding ASD), autistic students (ASD), and whether the student actively participated in the game. Models 2 and 4 additionally control for attendance (percentage) and academic performance (GPA on a 1–7 scale). All models include classroom fixed effects and cluster-robust standard errors at the classroom level. Attendance and GPA data were available for 409 of the 530 students CI = Confidence interval; LL = Lower limit; UL = Upper limit; SE = Standard error *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

caution due to the very small sample size in this model. The adjusted R^2 of 0.038 indicates limited explanatory power and predictive accuracy of the estimation.

In sum, these results indicate students with SEN and autistic students, consistently engages in fewer reciprocal exchanges and is associated with a lower likelihood of reciprocal choices among pairs of students. The results are robust for autistic children, and less robust for children with SEN. These significant results are consistent when estimated with a logistic model (see Supplementary Table S8).

Characteristics of autistic students. Clustering analysis

Finally, to gain deeper insights into the social interactions and integration of autistic children in our sample, we conducted a cluster analysis to further characterize them, using centrality measures of PageRank, Betweenness and Closeness. We utilized k-means clustering to examine and categorize their social interaction patterns within a game setting (For details, see Methods).

To explore the heterogeneity within the group of autistic children based on these centrality measures, we identified three distinct clusters (Supplementary Fig. S4a and S4b). Cluster 1 includes three children who exhibit high PageRank and Closeness centrality, indicating they are popular and can quickly connect with others in the network. Cluster 2 comprises four children with high Betweenness centrality, suggesting they act as key connectors or bridges between different groups within the network. Finally, cluster 3 consists of 11 children with low evaluations across all centrality measures, indicating a less central and potentially more isolated position within the network.

Although all the clusters included girls and boys, cluster 3 included only one girl from the 11 children that comprised it. Interestingly, this girl showed the highest Betweenness score within the cluster, which led us to question whether this feature could be similar to the girls in the other clusters. We address this question by comparing the Betweenness score between girls and boys, irrespective of the cluster to which they belong. A Wilcoxon rank-sum test showed that overall, autistic girls had significantly higher Betweenness scores compared to autistic boys ($p = 0.022$). Conversely, neither Closeness scores nor PageRank measures showed any statistical difference between sexes (Wilcoxon test, $p = 0.5$ and $p = 0.2$, respectively).

In addition, we examined these centrality measures in children with and without SEN. In the case of children with SEN, there was no statistically significant difference between sexes in PageRank (Wilcoxon test, $p = 0.7$) and Closeness (Wilcoxon test, $p = 0.2$) scores. However, in contrast to the group of autistic children, the Wilcoxon rank-sum test showed that girls with SEN had significantly lower Betweenness scores compared to boys with

Variable	Estimate	SE	95% CI LL	95% CI LL	P	R^2	Adj. R^2	N
Models for probability of a mutually reciprocated Choice								
Model 1- Senders without SEN						0.133	0.90	8607
SEN (exc. ASD) receiver	−0.064***	0.011	−0.087	−0.041	< 0.001			
Autistic Receiver	−0.166***	0.024	−0.214	−0.118	< 0.001			
Model 2- Senders with SEN						0.131	0.086	2343
SEN (exc. ASD) receiver	0.048*	0.024	0.001	0.095	0.045			
Autistic Receiver	−0.014	0.065	−0.143	0.114	0.825			
Model 3- Autistic Senders						0.137	0.086	218
SEN (exc. ASD) receiver	0.094	0.070	−0.061	0.249	0.208			
Autistic Receiver	0.348	0.329	−0.386	1.081	0.316			
Model 4- Senders without SEN						0.104	0.060	8607
SEN (exc. ASD) receiver	0.045***	0.013	0.020	0.071	< 0.001			
Autistic Receiver	0.112**	0.039	0.036	0.188	0.004			
Model 5- Senders with SEN						0.102	0.055	2343
SEN (exc. ASD) receiver	−0.002	0.030	−0.062	0.058	0.950			
Autistic Receiver	0.0001	0.079	−0.158	0.157	0.999			
Model 6- Autistic Senders						0.091	0.038	218
SEN (exc. ASD) receiver	−0.07	0.065	−0.215	0.076	0.310			
Autistic Receiver	−0.337**	0.092	−0.543	−0.131	0.004			

Table 3. Linear regression models for reciprocity at the dyadic level. Six linear regression models examine the probability of mutual peer selection (Models 1–3) and non-mutual peer selection (Models 4–6) among students. Models are grouped by sender type: students without SEN, students with SEN (excluding ASD), and autistic students (ASD). The dependent variable is a binary indicator of whether a mutual selection occurs (Models 1–3) or does not occur (Models 4–6) between each dyad. Independent variables are binary indicators of whether the receiver has SEN (excluding ASD) or is an autistic student. All models include sender fixed effects, classroom fixed effects, and cluster-robust standard errors at the classroom level. CI = Confidence interval; LL = Lower limit; UL = Upper limit; SE = Standard error. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

SEN ($p = 0.02$). For children without SEN, there was no statistically significant difference between sexes in PageRank (Wilcoxon test, $p = 0.9$), Closeness (Wilcoxon test, $p = 0.9$), or Betweenness (Wilcoxon test, $p = 0.5$).

Taken together, these results highlight the nuanced roles of individual nodes in network dynamics. However, these findings should be interpreted with caution due to differences in sample sizes across the groups and the heterogeneity among the children.

Discussion

In this study, we explored the role of certain neurodevelopmental variations in the formation of social interaction networks in elementary classrooms. We tested the hypotheses that, compared to both children with and without SEN, autistic children are more frequently located on the periphery of their peer social networks, and engage less in reciprocal relationships. We identified and analyzed both centrality and reciprocity measures by analyzing an experimental computational game designed to be played by children in the schools. The results obtained revealed distinct patterns related to the SEN condition of each child.

The inclusive perspective that we adopted here highlights the importance of recognizing that inclusion is a relational process. In this respect, although the small sample size of autistic students in our study limited the statistical power for individual comparisons between autistic children and children with SEN, the use of network and reciprocity analyses allowed these issues to be addressed by considering the links formed among all groups rather than analyzing nodes in isolation. By studying autistic students and students with SEN across all schools, the network and reciprocity analyses underscore how children are embedded in their classrooms and how their peers react to them. Network analysis thus enables a turn from examining individual attributes to understanding how relationships are constructed collectively within the classroom. This approach opens the possibility of conceptualizing inclusion not merely as an individual trait, but as a relational phenomenon that unfolds within social contexts.

In this context and in line with our hypothesis, our results showed that children with SEN as well as autistic children, exhibited a lower degree of centrality compared to non-autistic children. This means they were less frequently chosen and received fewer stars from their peers, indicating lower social standing and integration within their classroom networks. The association between autism and lower social standing remained consistent across different statistical models, highlighting the robustness of these findings. Importantly, our analysis evidenced that this statistical trend could not be attributed to a pattern of unequal distribution among the children. In this respect, the Gini coefficient revealed no significant differences in how stars were allocated among autistic and non-autistic children. Considering that, overall, children tended to distribute stars equitably, the association of SEN and autism with lower social standing highlights the vulnerable context of these students in social relationships. These results are consistent with previous findings, which indicate that autistic children are especially vulnerable to peer difficulties due to their challenges in recognizing, acknowledging, and communicating about concerning social situations[15–18,31–33].

In addition to the factors that negatively correlate with centrality measures, we also identified several variables that positively influenced students' centrality, and the number of stars received, both among students with SEN and autistic children. In this regard, active participation evidenced that students who were actively engaged in choosing classmates and sending stars were more central and preferred by their peers. Attendance and grades also significantly influenced centrality, and the number of stars received, suggesting that regular attendance and academic performance are important factors in peer acceptance and social standing. These results are in accordance with previous findings that have shown the relationship between social standing and academic achievement[34–37]. This underscores the significant role that social integration and acceptance play in shaping academic outcomes for all students.

Concerning the analysis of reciprocity measures, our results showed that children with SEN, especially autistic children, engaged less in reciprocal relationships compared to their peers without SEN and those with SEN excluding autistic children. However, the statistical dyadic models explained a moderate portion of the variance in reciprocal exchanges. This could indicate two possible interpretations. First, the small sample size of the autistic students is affecting the statistical power to detect group differences between autistic children and children with SEN. Second, while neurodevelopmental variations are significant factors, other variables also influence reciprocity in social dynamics within educational settings. Certainly, reciprocity is a complex social phenomenon. In this respect, two lines of research can be considered. First, that autistic individuals often experience significant challenges in establishing reciprocal relationships, due to differences in mentalization—such as thoughts, desires, and intentions—toward oneself and others[9,10,38–41]. Second, these challenges in reciprocity arise from a lack of alignment between an autistic person and a non-autistic person, i.e., the failure to share the same frame of reference regarding social reality, which creates a gap in mutual understanding[13]. As a result, these challenges can lead to misunderstandings in social interactions and hinder the development of mutual, two-way relationships that are critical for meaningful social integration. Reciprocity in social interactions is essential as it forms the foundation of trust and cooperation, which are key components of social networks within educational settings[2,3]. When children are able to engage in reciprocal exchanges, they are more likely to be accepted and integrated into their peer groups, which not only supports their emotional and social development but also contributes to a positive and inclusive classroom environment[37,42,43]. Therefore, fostering reciprocal relationships is a crucial step in promoting social integration for autistic children, as it helps bridge the gap between these students and their peers, leading to a more cohesive and supportive educational community.

Importantly, it is crucial to acknowledge that the social challenges faced by autistic children are not solely attributable to them. The reciprocal nature of social understanding suggest that difficulties can arise from a mismatch in communication styles and expectations between autistic and non-autistic individuals[13]. An ecological perspective should emphasize that social integration is influenced by the attitudes, understanding, and acceptance of peers, educators, and the broader school environment. Therefore, future interventions should not only focus on supporting the social skills of autistic children but also on fostering greater understanding and acceptance of neurodiversity within the educational community, thereby creating a more equitable and inclusive environment for all[1,2,22,23]. Moving beyond a narrow focus on autistic students' "deficits," future research should address a fundamental question: 'Who are we talking about when we talk about inclusion?' Studies should be aware of cultural and socioeconomic contexts, beliefs, attitudes, and behaviors of students, families, and educators, recognizing that inclusion requires a shift in the broader school culture, not just adjustments from autistic individuals. Addressing the reciprocal nature of social understanding is crucial; research should explore how a lack of mutual understanding between autistic and non-autistic individuals contributes to social challenges, emphasizing relational dynamics and the need for interventions promoting mutual understanding and empowerment. While focusing on the needs of all students, it's crucial to acknowledge the significant numbers facing segregation due to ability, economic status, or social factors, as well as those experiencing marginalization or mistreatment. Addressing these broader issues of inequity and school disengagement is essential for creating truly inclusive educational environments. This involves exploring how existing prejudices and hesitancy within the social environment may present barriers to autistic students and identifying strategies to foster a more inclusive and accepting community for all[2,13,23,44].

Regarding cluster analysis based on centrality measures, the identification of three clusters of autistic children, each with specific features, can shed light on the heterogeneity of the autism spectrum as well as the role that each child can play in social integration. These findings highlight the importance of recognizing the unique characteristics of each child within their social networks to develop comprehensive interventions. Additionally, sex differences were observed among the groups in the cluster analysis. While in the group of children with SEN (excluding autism), girls had significantly lower Betweenness scores compared to boys, in autistic children the opposite pattern was observed: autistic girls exhibited significantly higher Betweenness scores compared to autistic boys. As we previously mentioned, this result should be interpreted with caution, because Betweenness can reflect either bridging roles or peripheral positions in the network that facilitate the communication between different parts of the network. Notably, among children without SEN, no significant sex differences were found in any of the centrality measures, suggesting a more uniform pattern of social integration regardless of sex.

It is now known that there are several behavioral differences between autistic girls and boys that, combined with the tendency of females to effectively mask their "autistic traits", make it more challenging to accurately identify females with an autism diagnosis[45–52]. Social camouflage has been defined as the implementation of strategies used to appear "less autistic" in social interactions and contexts[46,52,53]. Interestingly, recent evidence showed that autistic girls exhibited higher reciprocity behaviors than autistic boys, despite their similar parentreported behaviors, reciprocal social interaction skills, and communication skills, revealing a "behavioral camouflaging"[52]. Based on these previous findings, the sex differences that we found in our clustering results could be revealing certain social strategies that girls might be using that are making them "bridges" between different parts of the network. However, since camouflage can be experienced as stressful, confusing, and energetically draining[54], teachers and parents should be attentive to any signs of stress or emotional and academic difficulties, regardless of how socially integrated a child may appear to others.

In sum, the analysis of clusters underscores the complexity of the varied social dynamics and individual roles that autistic children can have within their peer networks. Together with the results obtained in the analysis of centrality and betweenness measures, our results showed the heterogeneity in social integration and the distinct roles of autistic children.

Our findings contribute to the understanding of social interactions in educational contexts and foster the development of integration and coexistence policies that promote inclusive and supportive classroom environments for all students, particularly those with SEN and autistic students. The achievement of an inclusive education is often challenged not only by cultural variables but also by the implementation of segregated educational systems, which undermine practices that promote an education without exclusion[2,3,55]. Merely placing autistic students, as well as those without learning barriers or neurodevelopmental variations, in inclusive classrooms without proper support not only could fail to foster their social skills development and peer relationships but also could increase the risk of experiencing victimization and difficulties[18]. This issue underscores the importance of providing education on students' diverse support needs for students, families, and the entire school community. By fostering an inclusive environment that promotes understanding and acceptance, we can enhance social interactions for autistic students and create a more supportive community for everyone, including teachers, children and their families. Ultimately, this collective effort can lead to richer social experiences and a greater sense of belonging for all individuals, regardless of their differences[2,3,22]. Our study points out the need for larger, more comprehensive studies with detailed information on participants' characteristics and educational outcomes. Future research should consider these limitations to provide a clearer understanding of the social dynamics and educational experiences not only of autistic children, but also of all children.

Furthermore, our findings underscore critical challenges for teachers in creating truly inclusive classrooms for autistic students. Evidence has consistently shown that inclusion alone is insufficient to ensure positive social outcomes, highlighting the potential benefits of specific and directed strategies[56,57]. General education teachers would benefit from targeted training and ongoing support to implement thoughtfully designed support systems and evidence-based social skills interventions that are tailored to meet the unique needs of autistic students. Gaining a comprehensive understanding of the complexities of social-emotional relationships and classroom dynamics could foster inclusive environments that alleviate loneliness and promote meaningful friendships. Therefore, future research should prioritize supporting general education teachers with the tools and resources they could need to effectively facilitate the social integration of autistic students and promote a classroom culture that values neurodiversity.

This study has limitations that should be considered when interpreting the findings. The small sample sizes for the ASD and SEN groups reduced sensitivity to detect differences and may have led to an overestimation of effect sizes. A larger sample of autistic children would strengthen the reliability and impact of these findings. Although the approximately 3% of autistic children in our sample aligns with prevalence studies[58–61], it is more important to point out that not all classrooms included children with a confirmed diagnosis of autism. Furthermore, the study's design prevented us from examining specific characteristics of the autistic students, such as co-occurring conditions and intellectual performance. Understanding these variables could provide valuable insights into group and dyadic dynamics, contributing to a more comprehensive understanding of social preferences.

The context of the pandemic revealed significant challenges faced by schools, including inequities and barriers impacting teachers and, more importantly, students[62,63]. These issues complicated lesson planning, learning assessment, and attendance recording, leading to incomplete data on grades and attendance for all participants. To address these challenges, we implemented classroom fixed effects and standardized the results, which demonstrated robust findings across models that support our analysis. Additional analysis revealed that the effects of the pandemic were more pronounced in fully virtual classrooms compared to those conducted in-person or in hybrid settings. While this was not the primary focus of our study, it highlights the important role that learning environments can play in students' social integration and educational experience. Taken together, these findings provide valuable insights into how different learning environments influence student outcomes, particularly in times of crisis and uncertainty. It is important to note that social and cultural inequities and barriers affected all students, their families, and the broader educational community. These disparities not only hinder the ability of students to receive necessary support but also perpetuate cycles of disadvantage, potentially impacting their long-term educational and emotional outcomes. Further research is needed to shed light on educational gaps and inform the creation of equitable learning environments for all students.

Methods
Ethics statement
All methods and the experimental protocol were approved by the Universidad del Desarrollo Ethics Committee and met the principles of the Declaration of Helsinki and the Local Ethical Guidelines for Research Involving Human Subjects. All the parents/legal guardians of the students gave their informed consent, and the children provided their assent to participate voluntarily. These consent processes and all procedures were conducted in compliance with Chilean national legislation, institutional guidelines, and the Declaration of Helsinki. Specifically, parents/legal guardians and children were fully informed about the purpose of the study, the procedures involved, potential risks and benefits, and their right to withdraw from the study at any time. Children's responses were

Grade	Enrolled students	Students with parental informed consent (% of enrolled students)	'Active players' (% of students with informed consent)	Students with SEN with parental informed consent (% of students with informed consent)	'Active players' with SEN (% of students with SEN with informed consent)
First grade	196	183 (93.4%)	154 (84.2%)	42 (23%)	34 (80.9%)
Second grade	170	151 (88.8%)	124 (82.1%)	40 (26.5%)	28 (70%)
Third grade	183	161 (87.9%)	140 (87%)	42 (26.1%)	33 (78.6%)
Fourth grade	156	130 (83.3%)	112 (86.1%)	37 (28.5%)	31 (83.8%)
TOTAL	705	625 (88.7%)	530 (84.8%)	161 (25.8%)	126 (78.2%)

Table 4. Sample description. The study population included all students whose parents provided informed consent. Consequently, the proportions for 'Active Players' (students who were both senders and receivers in the game) and 'Students with SEN with parental informed consent' were derived from the total number of students with parental informed consent. There were no significant differences among grade levels in any of these groups, as indicated by the ANOVA test ($F = 0.228$, $p = 0.876$).

kept completely confidential, and their names were replaced with alphanumeric codes. Participating schools received a written report on the results of their students' participation, preserving the anonymity of individual participants, and a special education teacher designed strategies aimed at promoting inclusion. Additionally, a verbal feedback session involving the responsible researcher, the project coordinator, and the special educator took place to clarify the results and delve into the strategies as necessary.

Sample

Our sample consisted of 625 children in the first through fourth grades attending schools located in urban areas of Chile (see the Participants section for more details).

This research was conducted from July 2021 to May 2022. Due to the COVID-19 pandemic, throughout the year 2020, schools in our country experienced lockdown restrictions, transitioning to in-person classes intermittently in 2021[62]. In 2022, the lockdown restrictions were lifted. All students who participated in this study experienced periods of confinement and were part of a virtual classroom at some point in their academic life. This situation also affected participation in the experimental game. Among the 26 classrooms included in our study, 12 participated entirely in-person, 8 entirely online, and 6 followed a hybrid format, with some students attending in person and others participating virtually at the same time. We accounted for this variability in teaching modality by including it as a control variable in our analysis (see Supplementary Table S6).

In the specific case of the classrooms that participated in our study, none of them were separated before playing the game. Given that our sample included children from 1st to 4th grade, it was a requirement that the majority of students had been together either at the beginning of the year (for those who participated at the end of the academic year) or for at least one year prior (for those who participated at the beginning of the academic year).

Participants

A total of six elementary schools participating in the Chilean National Program of School Integration (in Spanish PIE, Programa de integración Escolar) took part in this research. Schools in this program receive support to implement an inclusive strategy aimed to contribute to the continuous improvement of the quality of education provided in the educational institution, promoting the presence in the classroom, participation, and achievement of learning objectives for every student, especially those with SEN[55]. The program defines general guidelines, but each school board manages implementation details. In this regard, as part of the PIE program, students with SEN are primarily integrated into general education classrooms with their grade-level peers. In some cases, students may also receive specialized support in separate settings for certain periods of the day, depending on their individual needs and the school's resources.

These participating schools had two types of administrative dependency: four were municipal schools and two were privately subsidized institutions. Municipal schools are funded through state subsidies, while privately subsidized schools receive funding through a shared financing model, which consists of state resources and payments made by each family[64].

A total of 26 classrooms from 1st to 4th grade participated in the study (Table 4). The average number of students per classroom was 27.12, with a median of 27 (ranging from 16 to 39). Therefore, from a total of 705 enrolled students, 625 parents (88.7%) consented to their children (between 6 and 11 years old) to participate. Of those who consented, 161 were children with SEN (25.8%; 18 autistic children) (Table 4). Among the consented participants, 143 children were students with SEN excluding ASD (22.2% of the total study sample). A chi-square test was performed to examine the distribution of different SEN categories within the group of students with SEN excluding ASD. The categories considered were specific language disorder (11.8%), intellectual disability (4.64%), specific learning disorders (3.52%), attention deficit disorder (1.76%), motor disorders (0.48%), hearing impairment (0.16%), and multiple disabilities (0.48%). The results of the chi-square test indicated a significant difference in the distribution of these SEN categories across classrooms ($\chi^2 = 196.77$, $df = 6$, p-value $< 2.2e-16$), suggesting that the distribution of SEN categories was not homogeneous across the sample. Grades and attendance records were provided by the schools (for details, see Supplementary Table S1). All participants were Spanish speakers.

In order to conduct the game session in each classroom, a headshot photograph of each participant was required to be integrated into the game interface. Therefore, when parents/legal guardians provided their informed consent for the students, they were requested to submit a headshot of their child to the school. It is important to note that some students did not participate in the game despite having their parents' informed consent due to various reasons (e.g., illness, loss of interest, difficulties with internet connection, etc.). As a result, the final sample of participants included two categories of game players: i) Active players, referring to children who played the game, and ii) non-active players, referring to children who were unable to play the game for any reason, but their headshots were present in the game interface to be selected and receive stars.

Power analysis via simulation

To evaluate the statistical power to detect group differences in our sample with unequal group sizes ($n_{ASD} = 18$, $n_{SEN} = 143$, $n_{withoutSEN} = 484$), we conducted a simulation-based power analysis. We used standardized effect sizes (Cohen's *d*) to define the expected differences between groups: $d = 0.3$ for ASD vs. SEN, and $d = 0.6$ for ASD vs. without SEN. The analyses showed high overall power to detect any group differences (93.9%) using a global ANOVA. However, power was more limited for specific pairwise comparisons: 70% for ASD vs. without SEN and only 21% for ASD vs. SEN. These findings indicate that the current design lacks sufficient sensitivity to reliably detect small differences between the ASD and SEN groups. As a result, any significant effects observed in this comparison may overestimate the true effect size. Therefore, replication with a larger sample of autistic children is essential to confirm findings related to this contrast.

Experimental task: the game of the stars

A computational distribution game based on experimental game theory[24,25] was created to construct the social networks of students. The game is self-contained, lasting 5—7 min, with written and audio instructions. It can be played at home or in the classroom, accessible from any internet-connected device. The game ensures the anonymity of responses and operates as a platform online rather than as a standalone application.

Before the game started, a video containing all the instructions was displayed to explain the rules to the children regardless of their reading level. All subsequent instructions were presented in both text and audio formats to maintain this accessibility measure. Children provided their informed assent through the game interface by answering the question, "Do you want to play?".

The game comprises four stages:

(1) Real Effort task: The game starts with a real effort task to earn 15 stars, requiring children to pop 15 moving bubbles to earn stars. The rationale for including this stage was to captivate the child's interest in the game by providing an interactive experience and allowing them to actively participate in acquiring something, establishing a sense of ownership of what would be shared with another person[24,25].
(2) Choice of classmates: After completing the effort task, a screen displaying individual headshots of each classmate appeared. To ensure accessibility and equal opportunity for all participants, regardless of their technology proficiency, the scrolling through the classmates' headshots occurred automatically at first, showcasing all classmates. Children were then instructed to manually scroll through the screen to choose 10 classmates to play with (Fig. 1a).
(3) Stars allocation: After selecting their 10 classmates, children were instructed to allocate the 15 stars earned in the Effort Task stage to the chosen classmates (Fig. 1b). The interface prominently displays the headshots of the 10 selected classmates, ensuring all are visible for thoughtful decision-making during star distribution. This setup facilitates recognition, recall, and evaluation of social preferences within their network.
(4) Peers' nomination: Once the game was finished, three additional screens were presented to the children to answer: Which of these classmates are you willing to hang out with? Which of these classmates do you not want to hang out with? Which of these classmates are your friends? These screens used a similar interface to the choice of classmates' stage. None of these three questions had a limit on the number of classmates that could be nominated. Children had the option to choose some of their classmates, none of them, or all of them. This instruction was explicitly stated to the children in each case.

After the child completed the game, a coloring book with star motifs was given to them as a thank-you gift for their participation.

Game restrictions and incentives

The game was designed with two key restrictions to compel students to make meaningful choices, regarding partner selection and star allocation.

First, in the stage of choosing classmates, children must select 10 partners from among all their peers to progress to the next stage. This mandatory selection was conducted independently of any prior actions, nudging students to form a social group of 10 peers.

Second, during the star allocation stage, children must distribute 15 stars among 10 chosen classmates. They had total freedom in their allocations, with the option to give any number of stars, from none to all, to any peer. The challenge was to distribute an odd number (15) among 10 recipients, requiring unequal distribution. To distribute equally, at least 5 classmates would receive an additional star. This arrangement challenged children's tendencies toward fairness and equality[65–67]. Furthermore, the choice of 10 peers allows for the inclusion of both close connections and broader interactions within their peer group[68,69].

The non-anonymous nature of the game mirrors real-life social interactions, where decisions are influenced by existing relationships and past interactions[70,71]. By allowing a range of preference levels (0 to 15 stars), the game captures a nuanced spectrum of social interactions. This setup, grounded in game theory principles and previous research[34,72], offers an age-appropriate format for students to express their social preference tendencies. Observing how students navigate resource allocation within their peer groups provides insights into the influence of pre-existing relationships on their choices and the overall social dynamics in classrooms.

Centrality measures

Centrality quantifies a student's position within the class network, reflecting their peers' preferences based on the choices and resource allocations they receive. We analyzed centrality in both the 'player choice network' and the 'stars allocation network', as follows:

Choice network centrality

In order to quantify the association between children's centrality in their peer groups (either in terms of receiving choices or stars) and their student group (i.e., autistic students, students with SEN, or students without SEN), we estimated linear regression models using the following general specification for student *a* in class *j*:

$$\begin{aligned}\text{Centrality}_{aj} = &\beta_0 + \beta_1 \text{SEN (excl.ASD)}_a + \beta_2 \text{ASD}_a + \eta_j \\ &+ \beta_3 \text{Active Player}_a + \beta_4 \text{Attendance}_a + \beta_5 \text{Grades}_a + \varepsilon_{aj}\end{aligned} \quad (1)$$

This model incorporates indicators for students identified with a SEN condition, excluding those autistic students, as well as a separate diagnostic indicator for autism. Class fixed effects η_j are included to accounts for characteristics that are constant within each group, such as the average level of interaction in the game, the head teacher's influence, and the overall class social environment. Since in Chile, school selection is highly correlated with income and geographical location, these fixed effects also control for these factors.

The model also adjusts for covariates potentially correlated with both game outcomes and diagnostic assessments, including the student's active participation on the game day (active player), overall school attendance (attendance), and grade point average (grades).

Furthermore, considering that, in the stage of choice of classmates, each student must choose 10 classmates, the centrality measure in the choice network answers the question: if children are required to choose 10 peers, how often is a particular student included in these groups? In order to answer this question, we defined a Choice Average In-Degree centrality. This metric measures the number of times a student was chosen by peers within their classroom (line thickness in Fig. 1c). It serves as an extensive measure of centrality since all students are potential recipients of choices. This metric captures the popularity or social acceptance of each student within the classroom, averaged to allow comparisons across different classes (see Table S5 for details).

Stars network centrality

Considering that, in the stars allocation stage of the game, the students can freely distribute 15 stars among the 10 chosen classmates, this network provides a granular measure of relationships. This network is a subset conditional on selection, where stars sent are considered weighted directed links. Therefore, we defined a Stars Average Weighted In-Degree Centrality (In-Strength). This metric measures the total number of stars received by each student, calculated as the sum of the weights of incoming edges on average (size of each circle in Fig. 1c). It reflects the intensity of peer preference. This metric highlights how resources are distributed among the chosen peers and indicates the degree of preference or importance attributed to each student by their classmates (see Table S5 for details).

Combining these centrality measures provides a nuanced understanding of both the overall position (based on constrained choices) and the intensity of preference (based on star allocations) for each student. This comprehensive approach allowed us to assess how integrated a student was within their peer group and the strength and quality of their interactions.

In addition to these metrics, we also considered three specific centrality measures to further understand the characteristics of autistic students in detail. The additional metrics were defined based on the stars allocation as follows:

PageRank centrality: This measure was calculated using the PageRank algorithm, which assigns a ranking to each node based on the number and quality of incoming links, accounting for the broader network structure[73]. It can be considered as a proxy for social rank in the group[74] (see Table S5 for details).
Betweenness: Betweenness Centrality measures the extent to which a student lies on the shortest paths between other students. It represents the role of the student as a bridge or intermediary within the network, indicating their importance in facilitating communication and information flow between different parts of the network. This metric was defined as the sum of the proportion of shortest paths passing through the student individual *a*, considering all nodes that are not *a* and include two other peers (*m, l*) (see Table S5 for details).
Closeness: Closeness Centrality reflects how close a student is to all other students in the network, based on the shortest path distances. A high closeness centrality indicates that a student can quickly interact with all other students, suggesting a central position in terms of communication efficiency (see Table S5 for details).

Null model for filtering trivial game exchanges

To rigorously analyze the social dynamics in the Stars Game, we developed a null model filtering algorithm. This method randomizes recipient assignments while preserving each participant's total sending behavior—out-degree (choices) and out-strength (stars sent). By comparing observed interactions to randomized patterns, the algorithm filters out exchanges explainable by chance, ensuring that only statistically significant and meaningful interactions are retained for further analysis.

We randomized the networks to replicate the observed distribution of sending behavior, establishing a baseline for expected exchange patterns driven purely by general sending tendencies. This process is independent of strategic or preferential receiver selection, which could be influenced by biases linked to diagnostic groups. The algorithm employs out-degree-preserving randomization, which creates a robust benchmark to distinguish non-trivial cooperative patterns from those likely resulting from random token distributions. By preserving the total number of tokens sent by each participant, the method rewires edges while maintaining the observed network structure[75,76].

The process involves simulating the network by shuffling the sending vectors of each participant 1,000 times. For each exchange, a 95% confidence interval is calculated based on the randomized patterns, and observed exchanges falling within this interval—consistent with random behavior—are filtered out. The resulting filtered network retains only statistically significant links, highlighting interactions unlikely to occur by chance. This ensures the robustness of the analysis and the interpretation of social dynamics.

Reciprocity measures

Reciprocity examines mutual interactions within the network, focusing on whether students choose each other or send similar amounts of stars. This analysis was limited to students who were present on the day of the game and actively participated, as only these students had the opportunity to reciprocate interactions.

We defined two reciprocity scores for each student, one for the choosing stage and one for the stars stage. These scores, ranging from 0 to 1, quantify the overall proportion of reciprocated interactions a student was involved in considering their actions in the game.

Additionally, we analyzed reciprocity at the dyadic level by examining the probability of mutual selection between two students using regression models. This approach provides a more granular understanding of the likelihood of reciprocal choices (see Table S5 for details).

Reciprocated choice score

The r*eciprocated choice score* measures the proportion of mutual selections a student receives during the choosing stage, as a proportion of their selections in the game. To calculate this score, we identified pairs of students who select each other, forming bidirectional links (see Table S5 for details). The degree of a student is the total number of in and out links they have, representing all their interactions. This score ranges from 0 to 1, where 1 represents the case in which all interactions are reciprocal, and 0 indicates no reciprocal interactions.

Reciprocated stars (Weight) score

This metric measures the proportion of mutual exchange of stars for each student within the game, as a proportion of their star allocations in the game. If a student, classified as an active player, does not get selected by classmates, their star value defaults to 0. By aggregating the minimum number of stars exchanged with each peer[26] (see Table S5 for details). This metric provides insights into the depth of reciprocal interactions within the classroom by reflecting the degree of mutual investment in relationships.

Statistical models

We employed regression models to estimate the association between SEN, particularly autism, and network centrality and reciprocity metrics.

Considering that not all observed outcomes are necessarily a consequence to diagnosed neurodevelopmental conditions, estimated coefficients in multiple regression models could be biased. To mitigate these concerns, we statistically isolated the influence of SEN condition on students' centrality scores and reciprocity metrics by controlling for individual characteristics and incorporating fixed effects in the regression models that account for observed and unobserved characteristics within groups.

The base model for number of times a student *a* is chosen by their classmates in class *j* (C_{aj}) and received stars (S_{aj}) were:

$$C_a = \sum_{a \neq b} c_{ab} = \beta_0 + \beta_1 \mathrm{SEN}_{aj} + \gamma' X_{aj} + \eta_j + e_{aj} \tag{2}$$

$$S_a = \sum_{a \neq b} s_{ab} = \beta_0 + \beta_1 \mathrm{SEN}_{aj} + \gamma' X_{aj} + \eta_j + e_{aj} \tag{3}$$

where SEN_{ai} is a binary variable indicating if a student is identified as having SEN, X_{aj} is a vector of control variables including attendance, grades, and *a* is a variable indicating if the student was active in the game (present on the day of the experiment and a sender of choices and stars). η_j is the class-level fixed effect accounting for average constant effects in each classroom (e.g., class size, school, head teacher, grade level), and e_{aj} is the random error.

Additionally, we distinguished students with SEN by categorizing them into students with SEN that have a diagnostic of ASD and students with SEN without ASD using two indicator variables: *SEN (excl ASD)* is a Boolean regressor that takes the value 1 if a student is identified as having SEN excluding autistic students, and *ASD* indicates diagnosed autistic students.

$$C_a = \sum_{a \neq b} c_{ab} = \beta_0 + \beta_1 \mathrm{SEN\,(excl\ ASD)}_{aj} + \beta_2 \mathrm{ASD}_{aj} + \gamma' X_{aj} + \eta_j + e_{aj} \tag{4}$$

$$S_a = \sum_{a \neq b} S_{ab} = \beta_0 + \beta_1 \text{SEN (noASD)}_{aj} + \beta_2 \text{ASD}_{aj} + \gamma' X_{aj} + \eta_j + e_{aj} \quad (5)$$

For reciprocity, we first employed a similar fixed effects (FE) ordinary least squares (OLS) approach to estimate the impact of SEN category on the reciprocity of exchanges. This involves analyzing mutual exchanges within the network to understand how SEN condition affects the likelihood of reciprocal relationships.

$$RC_a = \beta_0 + \beta_1 \text{SEN} + \gamma' X_{aj} + \eta_j + \mu_{aj} \quad (6)$$

$$RC_a = \beta_0 + \beta_1 \text{SEN(exclASD)}_{aj} + \beta_2 \text{ASD}_{aj} + \gamma' X_{aj} + \eta_j + \mu_{aj} \quad (7)$$

We employed a similar approach for measuring the association between SEN category and reciprocity in the weighted network:

$$RS_a = \beta_0 + \beta_1 \text{SEN } + \gamma' X_{aj} + \eta_j + \mu_{aj} \quad (8)$$

$$RS_a = \beta_0 + \beta_1 \text{SEN (excl ASD)}_{aj} + \beta_2 \text{ASD}_{aj} + \gamma' X_{aj} + \eta_j + \mu_{aj} \quad (9)$$

Finally, to fine-tune our analyses, we observed the dyadic level exchanges patterns, particularly focusing on whether the probability of a reciprocal choice is associated with any neurodevelopmental condition.

$$P(C_{ab} = C_{ba} = 1)_j = \beta_0 + \beta_1 \text{SEN(exclASD)}_{aj} + \beta_2 \text{ASD}_{aj} + \theta_a + \eta_j + \mu_{aj} \quad (10)$$

where $P(C_{ab} = C_{ba} = 1)_j$ represents the probability that there is a mutual choice between student *a* and student *b* in class *j*. This means that student *a* chooses student *b* and student *b* chooses student *a*. The model includes the diagnostic of the receiving student *b* as the main explanatory variable, distinguishing between SEN excluding autistic students and autistic students. The fixed effects at the sender level θ_a and at the class level η_j are included to control for individual sender characteristics and class-level effects, respectively.

Cluster analysis

With the aim to identify and analyze the social profiles among autistic students, we employed k-means[77] clustering to describe and categorize the social interaction patterns on the game of autistic children focusing on key network centrality measures calculated based on the stars allocation and considering not being chosen (0) as equal as not receiving stars (0).

To define the number of clusters for our analysis, we employed the *elbow* method. This technique involves calculating and plotting the explained variation, or the sum of squares within the clusters, against the number of clusters. We looked for a point on the graph where the rate of increase in explained variation significantly diminishes, which is referred to as the "elbow." In our case, this inflection point occurred at three clusters (Supplementary Fig. S5).

We normalized PageRank centrality, betweenness centrality, and closeness centrality to ensure comparability. The k-means algorithm was then applied to partition the students into distinct clusters based on their network positions, providing insights into their diverse exchange patterns and social dynamics within neurodiverse classrooms.

To further explore potential sex-related differences in network centrality, we conducted post-hoc comparisons of centrality measures (Betweenness, Closeness, and PageRank) between girls and boys across three groups: autistic children, children with SEN excluding autism, and children without SEN. These analyses were performed using non-parametric Wilcoxon rank-sum tests due to the non-normal distribution of the data.

Data availability

All data and codes are available in the OSF repository (https://osf.io/bpm5g/).

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Declarations

Competing interests
The authors declare no competing interests.

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