Early-emerging representation of social networks

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Abstract

As adults, we mentally represent the social connections around us as a network. While imperfect, such representations help us navigate the complexity of our social environments. Yet, it remains unclear how such representations emerge in development. The current work examines the extent to which young children can accurately represent their social networks. We asked 3- to 5-year-old children to report their good friends in their preschool classroom (first-person networks) and with whom they think their classmates are good friends (third-party networks). Teachers also reported children's friendships within these classrooms. Social networks derived from children's third-party reports were significantly more aligned with their first-person and teacher-derived networks than simulated networks of a similar size, even after removing children's own friendships. Using an ecologically valid method, the current work provides evidence that humans, starting early in life, can systematically encode and represent their social networks.

Keywords: cognitive development; social networks; social cognition; social relationships; cognitive representation

Introduction

Social networks—the interconnected relationships among people—have been a topic of intense empirical interest for several decades (see Christakis & Fowler, 2009a; Mitchell, 1974). Research has revealed how the structure of our social networks shapes nearly every aspect of our lives, including our wealth, health, and happiness (see Christakis & Fowler, 2009b; Smith & Christakis, 2008). Recent evidence suggests that the way humans *think about* their social networks also shapes people's behavior in a wide range of contexts (see Basyouni & Parkinson, 2022; FeldmanHall et al., 2025).

A growing body of work has found that by adulthood, humans encode both the specific relationships that comprise their social network (e.g., Feltham et al., 2025; Teoh et al., 2025) as well as people's relative position within the broader network (e.g., popularity; see Parkinson et al., 2017; Schwyck et al., 2023; Weaverdyck & Parkinson, 2018). These representations play a fundamental role in how people think about their own and others' relationships (Son et al., 2021, 2023, 2024), infer others' mental states (Xia et al., 2025), and form social ties (Aslarus et al., 2025). Nonetheless, much remains uncertain about how our ability to represent social networks develops early in life. To what extent might young children represent other people's relationships, and how accurately do these representations reflect the underlying structure of their social network?

Representing social networks requires at least two cognitive capacities. First, one must be able to represent and reason about its constituents—social relationships—such as inferring other people's relationships by observing how they interact. Second, one must be able to connect multiple individual relationships into an integrated representation, resulting in a stable network-like structure. Representing connections between multiple relationships can be especially challenging in real-world contexts where social interactions are often ambiguous and the networks themselves are dynamic and fuzzy in scope.

There is evidence that by around 8 to 9 years of age, children have a broadly accurate, systematic understanding of their peers' relationships that reflects their network-like structure (Cappella et al., 2012; Kornbluh et al., 2025; Neal et al., 2014, 2016). Yet, the developmental origins of this ability remains unclear: When do children begin representing their own social relationships as a network, and how accurate are these representations? The current work examines whether even preschool-aged children can represent the social networks in their classrooms.

Early representation of social relationships

There is ample evidence that humans possess a nascent capacity to represent and infer other people's social relationships (see Thomas, 2024). By around age 1, infants expect two individuals to affiliate based on whether they speak the same language (Liberman et al., 2017), perform the same ritualistic actions (Liberman et al., 2018), have similar food preferences (Liberman et al., 2014, 2021), or imitate each other (Kudrnova et al., 2024). Impressively, infants also appreciate that not all relationships are created equal, distinguishing between "thick" relationships that involve more intimate actions—like saliva-sharing, caregiving, and comfort—and "thin" relationships that involve positive, but less intimate actions such as basic reciprocity (Thomas, Woo, et al., 2022).

Infants' understanding of relationships undergoes refinement with age. For example, by around age 5, children begin to make different predictions about how people will act around their family members versus their friends (Spokes & Spelke, 2016). Over the next few years, children's understanding of friendship becomes increasingly sophisticated (see Afshordi & Liberman, 2021), enabling them to infer that two people are friends based on how they distribute resources (Liberman

& Shaw, 2017), share knowledge (Liberman & Shaw, 2018), correct each other's mistakes (Yang & Liberman, 2025), and represent each other's mental states (Woo et al., 2025).

Overall, these findings provide strong evidence that the ability to represent and reason about people's social relationships emerges in infancy and develops rapidly throughout early childhood. However, this evidence comes primarily from lab-based studies that involve pairs of novel agents whose relationships are isolated from a broader network. Thus, they say little about when and to what extent children can reason about multiple interconnected relationships. Nonetheless, recent work examining children's knowledge about their caregivers' relationships hints at some understanding of the relationships in their immediate social network.

First, both infants and young children seem to understand that people affiliated with their caregivers are more likely to know them. For instance, 12-month-olds expect that a puppet who affiliated with their caregiver is more likely to know their name compared to a puppet who affiliated with a stranger (Thomas, Saxe, & Spelke, 2022). Likewise, when a stranger unexpectedly possesses knowledge about them (e.g., knows their favorite movie), four- and five-year-olds tend to explain how they acquired that knowledge by appealing to a relationship with their caregiver (e.g., "my mom probably told them"; Chuey et al., 2026). This suggests children represent their own relationship with their caregiver and are aware that their caregiver's relationships can connect them to others.

Second, there is evidence that young children possess knowledge about their caregiver's relationships. For instance, four- and five-year-old children expect their parents to seek comfort from their own parents as opposed to their in-laws (Steele & Thomas, 2025). Thus, by around age four, children appear to track at least some of the relationships in their immediate social environment.

Collectively, prior research suggests that some of the key capacities necessary to form social network representations are present even early in development. Starting in infancy, humans can represent and infer relationships between individuals; by at least early childhood, these representations encompass some of the relationships in their own social network—particularly those involving their caregiver—and support complex behavioral predictions and mental-state inferences. Nonetheless, the extent to which children can form integrated, network-like representations of people's relationships still remains unclear. Do children merely encode a handful of salient relationships, or are they sensitive to the network-like structure of their broader social environment?

The current work seeks to bridge this gap by examining preschool-aged (3- to 5-year-olds) children's understanding of their peers' friendships. This is the youngest age at which children in many western countries form peer networks (see Daniel et al., 2019; Johnson et al., 1997), making it an ideal population to investigate the origins and development of social network cognition. While a number of studies have examined the structure (Neal et al., 2017, 2022) and dynamics (Martin et al., 2013; Schaefer et al., 2010) of preschoolers' classroom social networks, these studies have primarily focused on measuring children's actual social networks. Thus, these studies leave open the possibility that young children—despite being able to *form* social networks themselves—are unable to mentally represent them. Here we investigate young children's cognitive representations of these networks.

Measuring social network representations

Research with adults (e.g., see Aslarus et al., 2025; Feltham et al., 2025) and older children (e.g., see Cappella et al., 2012; Kornbluh et al., 2025; Neal et al., 2014, 2016) has used a variety of methods to measure the accuracy of their network representations. One approach uses a two-session design. In an initial session, participants report their own relationships; in a second session, participants are asked to report the relationships of a subset of related and unrelated pairs derived from the first session (e.g., Feltham et al., 2025). A second approach uses a single-session design where participants are asked to identify relationships among a roster of community members, and then each individual's answers are compared to the collective responses of all other participants (e.g., Cappella et al., 2012). Participants are deemed more accurate insofar as their responses are more similar to their peers. A third approach uses a single-session design where participants provide both first-person (i.e., who are you friends with?) and third-party (i.e., who is friends with whom?) relationship nominations; each participant's third-party nominations are then compared against all other participants' collective first-person nominations (e.g., Neal et al., 2016). Each of these approaches are typically operationalized as surveys that participants complete at their own pace, sometimes with the help of a teacher or experimenter.

In our study, we used a modified version of the third approach that better accommodated the attentional capacity of preschool-aged children. Guided by an experimenter, participants nominated their "good friends" in class from a roster. Afterward, participants grouped their peers into groups of good friends and then identified any peers who had good friends outside those groups. Although less comprehensive than asking participants about each peer's friendships, this procedure significantly reduced task length. We compared children's first-person reports (i.e., a measure of the actual social network) to children's third-party reports(i.e., each child's representation of that network). As a complementary measure of the network created from the first-person reports, we also asked one of the teachers to nominate friendships in class.

To measure the degree to which children's reports accurately reflect their true network, we compared the alignment between children's network representations and the actual social network in their classroom (i.e., children's accuracy) or simulated networks of similar size (i.e., chance accuracy). If children's network representations align more with the actual social network than what we would expect by chance, this would suggest children have a meaningfully accurate repre-

Figure 1: Panels depict a child participating in each phase of the experiment. Self-friendship nomination: Participants identified their "good friends" in class from a selection of cards depicting their peers' faces and names. Other-friendship grouping: Participants sorted their peers into groups of people who were all good friends with one another, yielding a series of visually-identifiable friend groups. Other-friendship nomination: Participants were asked to identify anyone in class who had friends outside of their friendship groups, yielding additional, verbally reported relationships.

sentations of their peers' friendships.

Experiment

Methods

Participants Sixty-one children (Mean Age = 51 months [Range = 36-70], 26 females) from three classrooms at Bing Nursery School, a research preschool at Stanford University, participated in the experiment. The head teacher of each class also participated in an abridged version of the experiment. Most of these children spent approximately 3-4 hours per day in class for either 2 or 3 days a week.

Materials For each class, we constructed a set of laminated 2x2 inch cards with the pictures and first name of each student. An additional set of 10 cards with college-aged adults depicted the experimenter and their "class". Participants' responses were recorded using a video camera.

Procedure The experiment had three phases: self-friendship nomination, other-friendship grouping, and other-friendship nomination (see Figure 1). Participants sat at a table with cards depicting everyone in their class, including themselves. An experimenter told them they would be playing a game about friends. In the self-friendship nomination phase, the experimenter said: "Who are your good friends in class? You can point to everyone here who you are good friends with."

In the other-friendship grouping phase, the experimenter said: "Now we're going to think about who the other children in class are good friends with... I'm going to have you put everyone with their good friends. Let me show you how...". The experimenter then turned to their own class' cards, and placed a card depicting themselves with two others, saying "here's my good friends; we're all good friends with each other". The experimenter then created other groups of three cards, two cards, and a single card where they said: "This person doesn't have any good friends in class, so I'm going to put them over here by themselves". After they finished demonstrating, the experimenter invited the participant to put everyone in their class with their good friends.

Then came the other-friendship nomination phase, where the experimenter asked participants if any of their peers had other good friends in class. The experimenter demonstrated with their own class first; they pointed to one of the members of their class and said: "This person here is also good friends with that person over there". They then pointed sequentially at each card and either said they had another friend in class outside their group or that they did not. Next, they told the participant it was their turn to say if any of their classmates have any other good friends in class. For each classmate, the experimenter pointed to them and asked the participant "does [child's name] have any other good friends in class?"

Additionally, a teacher from each classroom completed an abridged version of the experiment that consisted of the other-grouping and other-nomination phases only.

Coding Participants' responses were converted to binary matrices (1=good friends, 0=otherwise). We used participants' aggregated self-friendship nominations to derive a composite social network for each class. For each participant, we used their other-friendship groupings and nominations to generate the participant's social network representation. The same procedure was used with each teacher's responses to yield a network representation for their classroom. Thus, each child had a "network representation" that was compared to a measure of the class' actual social network and their teacher's network representation (henceforth referred to collectively as "comparison networks"). Because we were only able to collect data from a subset of students in each classroom (25/36 for class A, 19/33 for class B, and 17/30 for class C), we took a conservative approach to constructing the composite network by attributing friendship to any pair of classmates so long as at least one of them nominated the other.

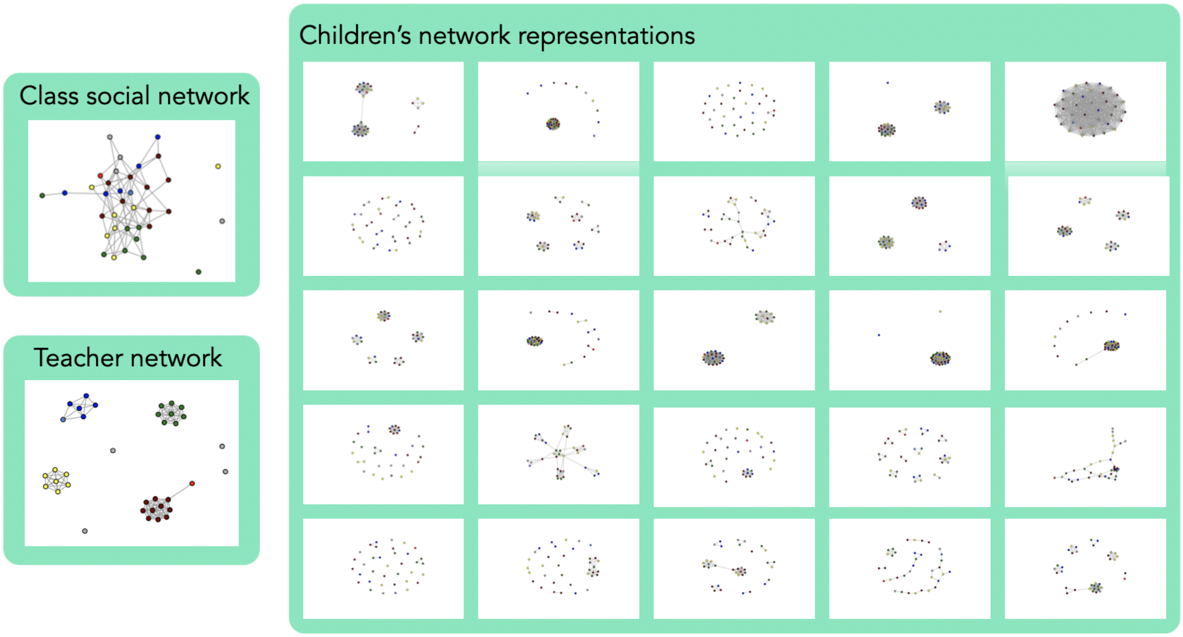

Figure 2: Class friendship networks for one class, generated from participants' aggregated self-friendship nominations and teacher report, as well as all network representations generated from children's other-friendship grouping and nominations (organized in ascending order by age). Individual nodes represent students in class, edges represent reported "good friends", and nodes are colored based on friend groups identified by the teacher.

Results

First, we examined whether children's social network representations were more closely aligned with the comparison networks than chance. We used Jaccard similarity as our measure of network alignment: the number of edges (friendships) two networks share divided by the total number of unique edges between them (see e.g., Tabassum et al., 2018). To determine chance-level alignment, we fit an exponential random graph model (ERGM) to each child's social network representation using the Network package in R (Butts, 2008), predicting the probability that any given pair will be friends based on the total number of friendships in the network. This null model of the data (analogous to a linear regression with only an intercept term) enables us to simulate networks with the same nodes (classmates) joined by randomly assigned edges. We generated 100 simulated networks for each child.

We then calculated the average Jaccard similarity between children's network representations and the comparison networks (alignment of interest), and compared it to the average Jaccard similarity between the simulated social network representations and the comparison networks (chance alignment) using a series of mixed-effects linear models. These models predict Jaccard similarity with network representation type (real vs. simulated) as a fixed effect and random intercepts fitted to each class. Overall, children's network representations were significantly more aligned with both comparison networks—the first-person network (β = .049[.034, .063], $p < .001$) and teacher's representations (β = .041[.021, .061], $p < .001$)—compared to their simulated counterparts.

Second, we tested whether these results hold when participants' own relationships are ablated. This ensures that children's accuracy is not simply driven by children having privileged knowledge of their own friendships. To do this, we conducted the same analyses as above, but removed any friendships involving a given participant from their network representation, comparison networks, and simulated networks. Even when they only contained peer friendships, participant's network representations were still significantly more aligned with the first-person network (β = .029[.015, .042], $p < .001$) and teacher's representations (β = .034[.014, .054], $p = .001$) compared to the simulated networks.

Third, we investigated the influence of three moderators on the accuracy of children's ablated network representations: age, children's familiarity with classmates (whether they were new to class that season), and their network centrality (i.e., eigenvector centrality calculated from the first-person network). For each moderator, we ran a pair of mixed effects models with network representation type (real vs simulated), moderator, and their interaction as fixed effects, with random intercepts fitted to each class. Across all models, there were no significant effects or interactions involving any of the moderators ($ps > .36$).

Finally, we examined the homogeneity of children's knowledge as an exploratory analysis. Although children's social network representations were more accurate than chance, the source of that accuracy is unclear: Were most children knowledgeable about the same relationships (e.g., friendships between a few particularly popular children), or did different children possess knowledge about different parts of their so-

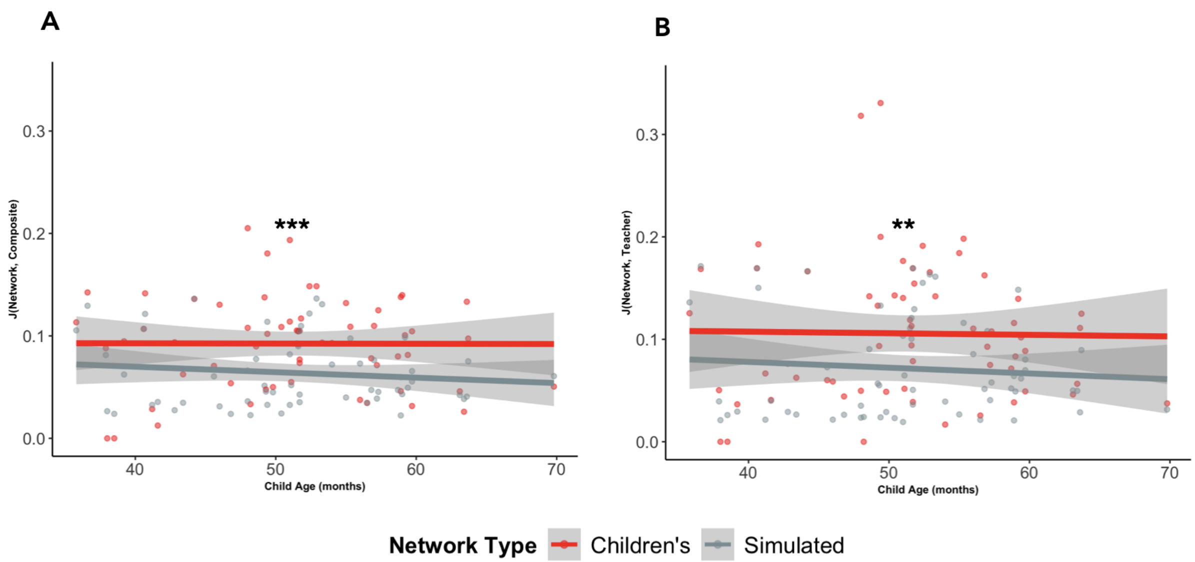

Figure 3: Jaccard similarity between participants' own network representations and two comparison networks (A: aggregated self-friendship network, B: teacher-reported network) across age, after ablating participants' own friendships. Error ribbons are 95% CIs; red lines indicate the alignment of interest (similarity between each comparison network and children's network representations), and gray lines indicate the chance alignment (similarity between comparison network and simulated networks of similar size with randomly assigned edges). Across all ages, participants' network representations aligned with the comparison networks significantly more than chance, even when children's own friendships were omitted from these networks.

cial network, much like adults do? If the former was true, children's accuracy should not improve much in aggregate, but if the latter was true, aggregating children's social network representations should yield a more accurate network than any single child in isolation.

To test this, we composed an aggregated network of the most commonly nominated n friendships in children's network representations for each of the 3 classrooms, where n represents the number of total friendships in a given classroom's social network. Comparing the alignment between these networks and the comparison networks yields Jaccard similarity metrics for each class, which can be compared to each class' average at the individual participant level. Interestingly, the aggregated Jaccard similarity was roughly double the average individual Jaccard similarity compared to both the first-person social networks (.2 vs .12, .18 vs .095, and .31 vs .12, for each class respectively) and teachers' representations (.22 vs .13, .16 vs .095, and .21 vs .1, for each class respectively). For reference, this is comparable to the Jaccard similarity between the teachers' representations and the first-person networks (.21, .16, .24, for each class respectively). This suggests that each child's network representation covers different parts of the broader social network, yielding greater collective knowledge when aggregated.

Discussion

For decades, scientists have used a variety of approaches to study how our social networks influence our lives. The present work explores a different question: How do humans *think about their social networks* from early in development? In particular, we examined not only the structure of young children's social networks at preschool, but also how much children knew about them. We found that by around age three, children's understanding of friendships in their classrooms meaningfully reflects their actual social networks. Importantly, this was not simply due to children tracking their own relationships, since they remained accurate even when their own relationships were not counted. This is especially impressive given that the children in our sample only spent 6-12 hours per week in a relatively large class (30 - 36 children), limiting their opportunities to learn about their classmates' friendships compared to typical preschool settings.

These findings provide insight into the developmental origins of a key part of human social cognition. A body of research with adults has found neural representations of relationships between individuals as well as more abstract features of the social network, such as how well connected people are (i.e., network centrality) and who tends to connect disparate groups within the network (i.e., brokerage; e.g., Morelli et al., 2018; Muscatell et al., 2012; Parkinson et al., 2017; Schwyck et al., 2023; Zerubavel et al., 2015). Yet, the extent to which these representations reflect an early-emerging understanding of relationships and social networks remains unclear. The current results suggest that by early childhood, humans not only represent and reason about individual relationships; they also represent them in a real-world social context, capturing its broader network-like structure.

To form accurate representations of their social network, children must be able to both 1) represent and infer other people's relationship based on observable evidence (e.g., how two people interact) and 2) integrate those representations into a stable, network-like whole. Prior work using well-controlled laboratory studies has shown that young children can reason about social relationships, and hinted at the possibility that they even possess knowledge about the relationships in their immediate social network. Building on these findings, the current work suggests that this knowledge extends to peer relationships in a complex, real-world social context.

What might be the potential consequences of early-emerging social network knowledge? A recent proposal highlights how our understanding of others' minds can inform inferences about social relationships, and vice versa (see Chuey & Gweon, 2025). On the one hand, understanding someone's mental states can help us make sense of their social interactions with others, providing a rich source of information for inferring people's relationships. On the other hand, knowledge about people's relationships can help us infer people's mental states. Because social relationships serve as channels for acquiring and transmitting information, an accurate representation of our broader social network supports accurate predictions about how a given piece of information will spread or who knows what about whom. While there is evidence young children use people's relationships to infer what someone might know about someone else (Chuey et al., 2026), the extent to which they can reason about the spread of information across their broader social network remains unclear and an exciting topic for future research.

Our study also has several limitations to consider. First, we were unable to collect data from every child in each class, rendering our measure of their social networks incomplete. Although children in our study demonstrated a reliable understanding of their social networks, this lowers the ceiling on the accuracy of children's friendship nominations. We took two measures to partially address this issue. One was to treat social networks as undirected—i.e., only one participant needed to report being friends with someone for that friendship to be counted in the network. Despite reducing the complexity of real-world friendships, which can be asymmetric, this increases the probability of detecting a friendship if one truly exists. The other was to use reports from the head teacher of each class—an adult familiar with its social network—as a complementary measure.

Second, our method of having children identify groups of friends and brokers between groups may have biased the structure of children's network representations towards having more or larger clusters of friends. Therefore, our analysis used Jaccard similarity—which captures the alignment between two networks in terms of their specific edges—as our measure of children's accuracy rather than a measure such as spectral entropy (De Domenico & Biamonte, 2016) that emphasizes alignment between broader network structures (e.g., average degree). Additional work is needed to assess whether children's representations capture structural elements of their social networks beyond the specific relationships within them.

Third, our study examined how a specific population (preschool-aged children in an affluent community) in a specific social context (a US preschool) thinks about a specific kind of relationship (good friends). This naturally limits the generalizability of our findings. Nonetheless, the present research does provide an "existence proof" for early competence in representing others' relationships: Under certain circumstances, children as young as 3 years show some sensitivity to their peers' social relationships. In fact, it is possible that children in other cultural contexts with community-based caregiving and peer groups fare even better than our participants (see Lew-Levy & Amir, 2024). More work is needed to understand the extent to which the present results generalize to other populations, social settings (e.g., neighborhoods), and types of relationships (e.g., kinship).

Finally, we did not find any reliable effects of age, time in class, or network centrality. This is somewhat surprising given prior work has that found age reliably impacts young children's understanding of friendship (e.g., Spokes & Spelke, 2016) and that network centrality strongly predicts adults' social network knowledge (Aslarus et al., 2025). Thus, more work needs to be done to understand the process by which children acquire social network representations and the factors that shape it.

There are many open questions about the underlying representations that drove children's responses in our study. Importantly, it is usually infeasible to represent social networks perfectly; both adults (see Aslarus et al., 2025; Feltham et al., 2025; Sehl et al., 2023; Teoh et al., 2025) and older children (Neal et al., 2014, 2016) are prone to systematic errors such as overestimating the social ties between kin or people with mutual connections. It is unclear whether young children might engage in similar strategies, such as overestimating friendships among those of the same age or gender. Moreover, it is still uncertain how network-like children's representations really are. Although children seem to know some of their peers' friendships—and even their broader cliques—they may still lack an adult-like awareness of the abstract properties within networks, such as people's network centrality and brokerage (see Basyouni & Parkinson, 2022). Future work that tests inferences only possible with these kinds of abstractions could speak to the underlying nature of children's representations.

Despite these limitations and open questions, the current work is an initial step towards understanding how young children represent their social networks. Leveraging the fact that children in preschool spend much of their time in a rich social network, our analyses revealed a precocious understanding of who's friends with whom: Going beyond merely tracking their own friendships or representing dyads of friends that remain unconnected with other relationships, children were able to represent the friendship among their classmates as a network.

While these early network representations may be relatively sparse and noisy, studying their developmental origins and change over time can shed light on how we, as humans, navigate some of life's biggest questions: Who am I connected to, who do I want to be connected to, and what do I do to form and manage these social connections? This research represents a first step towards understanding the origins of the human capacity to learn and reason about our social networks.

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