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Automating the analysis of social interactions in educational settings: a scoping review

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Abstract

Social interactions are crucial for children's development, attracting significant interest from educators and researchers. Traditional methods of data collection in educational settings have limitations, prompting the exploration of ICT devices for more accurate and efficient quantitative data collection. This systematic review, following the PRISMA framework, analysed 21 studies that used sensor devices to collect data on social interactions among children aged 0-12 in educational environments. The studies investigated various aspects such as interaction mapping, disease transmission, homophily, and play types, predominantly using observational or descriptive approaches. They were categorized into three levels of ecological complexity: (1) validation of sensor devices, (2) interaction analysis as a predictor of disease spread and vocabulary growth, and (3) examination of children's social dynamics. Findings indicate that sensor devices are particularly effective when combined with Social Network Analysis (SNA), which facilitates comprehensive analysis and graphical representation of social networks. Quantitative data on social interactions could help identify and support children facing exclusion or marginalization, allowing for targeted educational interventions. However, there is a notable gap in the literature regarding the use of sensor devices in educational interventions, underscoring the need for further research to evaluate their effectiveness and facilitate their application in education.

KEYWORDS: Sensor Devices, Assessment Technologies, Children Interaction, Educational Context, Social Network Analysis.

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1. Introduction

Social interaction is crucial for children's social, emotional and cognitive development (Casotti, 2022). Understanding the dynamics of social interactions within educational settings is essential for fostering children's overall growth. Research consistently demonstrates that the quality of the context profoundly impacts learning outcomes (Zöggeler-Burkhardt et al., 2023). Esteemed educational practices (e.g., Montessori and Reggio Emilia) underscore the importance of observation as a tool for professionals (Becker et al., 2023) to evaluate group dynamics and adjust educational strategies to foster the inclusion of all children. Despite their validity, traditional observation techniques face significant challenges. Observers cannot capture all the information in noisy settings like classrooms (Chun et al., 2011), and, as human beings, can be subject to personal and cultural biases (Pronin et al., 2023; Stubbersfield, 2022). Moreover, observation in educational settings require substantial resources in terms of training and time. Modern sensors technologies can overcome some of these limitations (Altman et al., 2020). Proximity tags,

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audio recorders, and cameras can capture vast amounts of accountable data from social interactions (Atzmueller et al., 2018) and, when combined with advanced data analysis methods like Social Network Analysis (SNA), can reveal unnoticed patterns. SNA is a well-established analytic approach for studying social relationships that has been implemented in various settings. Foundational to the development of SNA were the contributions of Jacob Moreno, who introduced the term "sociometry" to describe the measurement of social relationships. Moreno also developed the sociogram, a graphical tool representing the structural characteristics of a group (Felaco, 2019), that has been extensively utilised in educational settings to explore and visualise social dynamics among children via peer nomination (Jackson et al., 2022). However, the sociogram is subject to assessment-related limitations (Avramidis et al., 2017), which might be resolved using the aforementioned digital tools. This review aims to examine the extent to which the academic literature has addressed automated methods for observing and analysing social interactions in educational contexts.

2. Materials and Methods

The PRISMA framework was used for this literature review (Moher et al., 2009). An inquiry was launched on January 17, 2024. The search was conducted across four databases: PsycInfo, PubMed, Scopus and Web of Science. The following keywords string were used: AB ("social network" or "social interaction*" or child interaction or sociometry or "social status" or "social dynamics" or centrality or "core-periphery" or homophily or "social density" or "network analysis" or "organizational network") AND AB (kindergarten or "primary education" or "primary school" or elementary or child*) AND AB ("sensor network" or "interaction tracking" or "wearable sensors" or "sensing technologies" or proximity or "physical distance"). The inclusion criteria were: (1) automatic tool for data collection of social interaction; (2) simultaneous involvement of at least two children; (3) educational setting; (4) age range 0-12 years; (5) type of publication: peer-reviewed journal; (6) language: English; (7) research studies. Initially, 422 studies were identified; however, after the screening process, 409 were excluded for failing to meet the criteria. Additionally, 8 studies were identified through other systematic reviews (Elbaum et al., 2024; Horn et al., 2024), resulting in 21 relevant studies.

The full process is represented in Figure 1.

Based on their commonalities, we grouped the selected studies into three categories corresponding to increasing levels of ecological complexity. First, we present the studies that aimed at validating sensor devices compared to traditional techniques (Table 1). Second, we scrutinise studies analysing interaction as a predictor of diseases' spread and vocabulary expansion (Table 2). Lastly, we move to studies that employed those devices to analyse social dynamics and interactions among children within naturalistic educational environments (Table 3).

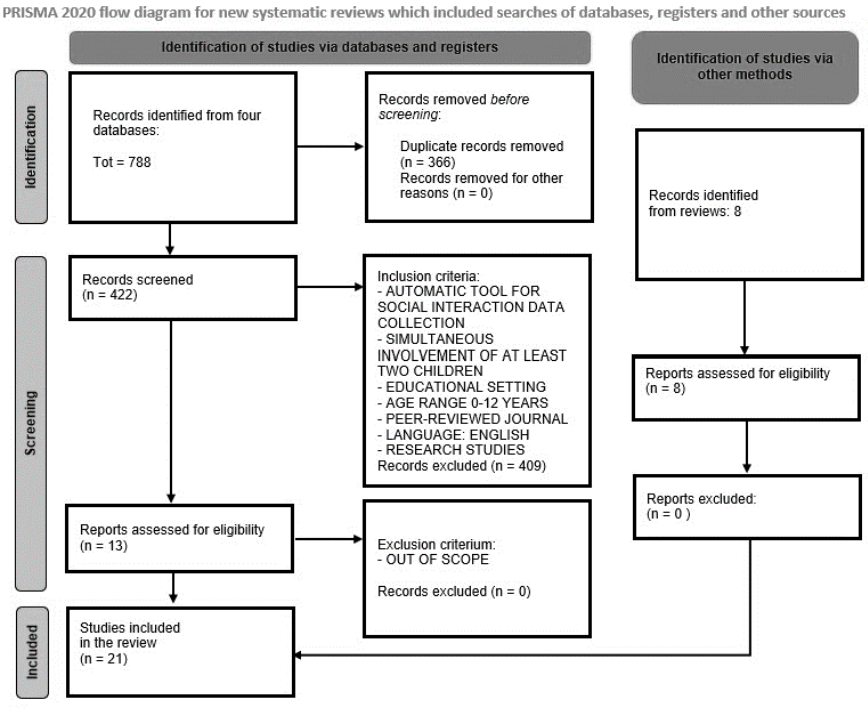

Figure 1 - PRISMA 2020 flow diagram.

3. Results

Although digital tools, such as cameras and audio recorders, have been widely used to support observational practices (Marsh & Mitchell, 2014), more sophisticated methods that integrate sensor devices with data analysis techniques and software have yet to be considered within educational settings. Among the scrutinised studies, some use cameras and audio recorders alongside analytical software to analyse video and audio data (Duan et al., 2017; Hansen et al., 2019; Irvin et al., 2021). Other studies propose using wearable devices (mainly radio wave technologies) to measure distances between people or between a person and a specific element of the environment. According to our knowledge, this type of device was first used in a higher education setting in 2003 and was introduced in the educational context 0-12 around 2011 (Choudhury & Pentland, 2003; Stehlé et al., 2011). Notably, 17 of 21 studies included in this review utilised this type of device. Depth-sensing cameras, such as the Microsoft Kinect, bridge these two typologies of technology by detecting spatial distances with greater accuracy than radio waves but with a more limited spatial range of detection (Komatsubara et al., 2018; Cocco et al., 2022).

3.1 Studies aimed at validating sensor devices

Compared to traditional techniques, data from the sensor devices provide a deeper understanding of children's social interactions, thus aiding in error identification and ultimately enhancing the validity of the research. Altman et al. (2020) compared the data of continuous social interaction with indicators of peer affiliation. Despite a limited sample size (9 children), the results show positive correlations between continuous measures of dyadic social interaction and teacher reports of friendship and sociability. Dai et al. (2020) analysed proximity data from wireless devices and validated them with ground truth data obtained with different methods, such as researcher observation of relative distances between children and teachers, achieving up to 90.03% accuracy. Duan et al. (2017) categorised children's social play using visual attention and proxemic cues based on head and hand detection. The system classified behaviours into solitary, parallel, and group play with an average head tracking accuracy of 95.73% and play-type classification accuracy of about 75%. Eichengreen et al. (2023) examined the changes in children's peer connections before and after the COVID-19 lockdowns, finding an increase in social interactions and diversity of play partners post-lockdown. The authors cross-referenced data obtained from wireless devices with data collected through peer nominations, observations, and self-reports to ensure accuracy and consistency in measuring changes in peer connectedness. Komatsubara et al. (2018) used face recognition and depth-sensing cameras with a social robot to estimate social status. The data gathered via devices were compared to an index of the sociometric status score derived from questionnaires, thus achieving an accuracy of 71.4%. Validation in the study by Grantz et al. (2021) involved comparing the data gathered by wearable proximity sensors with data collected from self-reported contact surveys. The study found good correspondence in aggregate measures of age-specific interactions; however, proximity sensors captured contacts more precisely. Nasri et al. (2022) employed wearable sensors to deduce social networks from individual behaviours during recess in two Dutch schoolyards. To confirm the precision and reliability of the sensor data, the researchers corroborated it with video recordings. The video data primarily corroborated the accuracy of recorded events and was reported as successful in confirming the presence of children in specific areas during recess.

3.2 Studies analysing interaction as a predictor of diseases' spread and vocabulary expansion

Some studies have examined the potential spread of infectious diseases or measured the evolution of language use and skills through interaction with other individuals. Although different, these two themes are united by their dependence on face-to-face interaction (physical or verbal). Authors are not concerned with particular social relations and dynamics; instead, they employ data from sensor devices to predict the likelihood of infection or the frequency of verbal communication. Leoni et al. (2022) used the Janus system (a wireless wearable device that combines UWB and Bluetooth) to collect high-resolution spatio-temporal data and monitor the interaction among small groups of children in Italian summer camps during the COVID-19 pandemic. They showed that proximity and duration of contacts can be used to analyse contagion risk effectively. In an earlier study, Stehlé et al. (2011) analysed the contact patterns between classrooms of a French primary school. Their findings showed that each child had, on average, three times fewer contacts with children from other classes. Turning to studies on vocabulary expansion, Perry et al. (2018) examined how verbal interaction among peers or teachers affected language use and development. Data was collected through a wearable device (LENA) capable of picking up vocalisations. The results show that verbal interactions between peers and teacher turn-taking were associated with increased vocabulary over a school year. Similarly, a study by Hansen et al. (2019) aimed to improve children's language development by analysing their verbal communication patterns. They combined a tracking device (Ubisense) with a vocalisation analysis tool (LENA) to track verbal production in different spaces of the classroom. They also used an optimised voice activity detection algorithm to reduce classification errors by 21.34% compared to conventional voice detection systems.

Their findings showed where and how children interacted verbally, revealing different levels of engagement with adults and peers, depending on the classroom's area and the times of the day. Perry et al. (2022) investigated the influence of peer vocalisations on language development in inclusive classrooms for children with and without hearing loss. The findings indicated that the frequency and intensity of vocal interactions among peers were predictors of improved language skills across all children at the end of the year.

3.3 Studies scrutinising children's social dynamics

To enhance the interpretation of children's social interactions, researchers often supplement sensor-collected data with information related to the specific time and location or about the children (e.g., sex or type of development). Veiga et al. (2017) examined the impact of different forms of social play, focusing on children's social competence between boys and girls. The authors combined wireless devices with observational assessments to analyse children's play behaviours during recess. Boys and girls participated equally in social play and no significant differences in social competence between boys and girls. Stehlé et al. (2013) explored similar dynamics with 232 French schoolchildren by examining gender homophily (i.e., the tendency to associate with peers of the same gender). They used wearable sensors to monitor face-to-face interactions and found that this tendency was more pronounced among boys, particularly in the 4th and 5th grades, and increased with age. Messinger et al. (2019) used wireless technology to monitor and analyse children's spatial and social dynamics in kindergarten, finding that students of different genders gathered in separate areas of the class and formed groups with little gender mixing. Nasri et al. (2023) tracked the spatio-temporal proximity between children in a schoolyard to study their social behaviours with a new metric, the "average spatio-temporal proximity". The findings indicated that children tended to interact with peers from the same groups and that the clusters of most open children used the common playground areas. Another focus in observing educational settings was the interaction between typically and atypically developing children. According to Banarjee et al. (2023), children in similar developmental condition dyads (typical development, TD and developmental disabilities, DD) approached each other faster and spent more time in social contact than those in mixed dyads (TD-DD). DD children were approached at lower velocities compared to TD children. Analyses also showed that social approach velocities correlated positively with the amount of time spent in social contact. Similarly, in the study by Fasano et al. (2021), children with autism spectrum disorder, ASD, engaged in fewer vocal interactions and occupied less central positions in classroom networks compared to TD peers. Studying friendship dynamics in young children, Irvin et al. (2021) found that children spent the most time and exhibited the highest vocalisation rates in a specific classroom area, suggesting that activity areas significantly influence spatial proximity and interactive behaviours. Cocco et al. (2022) conducted an imagined contact intervention to foster inclusion between typically and atypically developing children. Typically developing participants trained via imagined contact condition showed improved attitudes and increased helping intentions towards the outgroup compared to those in the control group. Iacopini et al. (2023) examined the socio-temporal patterns of group interactions in various educational settings, comparing interactions in preschool and university. The authors used an available dataset generated from wearables proximity devices and found that the chance of group changing is similar across the two different educational contexts; specifically, the older a group gets, the stronger it becomes, and the chance for an individual to change/exit it decreases.

4. Discussion and Conclusions

This systematic review aimed to locate examples of partial or complete automation of social and relational data gathering in educational settings. The reviewed research is recent (with the oldest studies dating back to 2011) but relatively scarce (only 21 studies met the inclusion criteria), indicating potential for further investigation. Sensor technologies are increasingly integrated into schools and classrooms; nevertheless, they are hardly used by/for professionals (e.g., educators and teachers) to support specific educational actions. The collected research suggests that sensors could provide more precise and objective data than conventional methods (e.g., Grantz et al., 2021). However, research does not assume an intrinsic validity of the data gathered by sensors. There is an understanding that a rigorous validation process is required (Dai et al., 2020). Several studies are dedicated to this endeavour, employing methodologies that juxtapose data collected via automated devices against "traditional" techniques. Data gathered from sensors have often shown good correspondence with other sources. This convergence enhances the validity of the findings obtained from these technologies and highlights their importance in inferring social networks from individual behaviours. Nevertheless, it remains to be seen if the existing research adequately supports the use of comparable sensor devices or whether new technologies should be subject to an analogous verification process.

Several studies employed SNA (Fasano et al., 2021; Grantz et al., 2021; Nasri et al., 2023).

Table 1 - Studies aimed at validating sensor devices.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Altman et al., 2020	USA	Observational-Descriptive	- Teacher social engagement reports - Teacher friendship reports - Peer likeability reports - Children friendship reports - Proximity interactions, orientation and vocalization	2 - 3	9	- LENA, wearables audio recorders - Ubisense, wearables and static sensors, UWB	Validating a method that combines proximity and vocal data into social interaction metrics.	The dyadic social interaction was positively associated with teacher friendship reports. The individual measure of social interaction correlated with children's likeability reports and teacher sociability reports.
Dai et al., 2020	France	Observational	- Physical proximity between children - Direct visual observation	2.5 - 6.5	170	- Sequanta, wearables and a central device, IoT-LPWD	Studying the co-evolution of children's language and social networks. Developing a method to model social interactions through data from wearable devices.	Temporal network reconstruction via LSTM models achieved up to 90% accuracy in reconstructing real interactions; naïve methods show the worst performance.
Duan et al., 2017	Cina	Observational-Descriptive	- Visual attention and proxemics of children calculated on head or hands without toys	Not specified	Not specified	- Static cameras - Hidden conditional random field - Support vector machine	Developing a method to categorise children's social play based on visual attention and proxemics cues.	Computation of proxemics and attention of children based on head detection and pose data showcased effective results in categorising children's play.
Eichengreen et al., 2023	Netherlands	Observational	- Proximity interaction and orientation - Duration and numbers of interactions - Direct observation - Peer nomination - Self-reports of loneliness - Self-reports of social contact in lockdown	8 - 12	43	- OpenBeacon, wearables, RFID and BLE	Comparing children's peer connections before and after COVID-19 lockdowns via different assessment methods.	Post-lockdown children showed more willingness to interact and play with a broader circle of peers.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Grantz et al., 2021	USA	Observational	- Self-reported contact surveys - Proximity interaction - Duration of interaction	5 - 18	2155 with contact surveys 1834 with sensor devices	- TelosB wireless wearables sensors	Understanding social interaction as indicator of disease transmission.	Proximity sensors recorded more contacts than surveys, but both methods effectively tracked age-related disease transmission trends.
Komatsubara et al., 2018	Japan	Observational	- Time spent alone - Distance outside personal area - Time spent around the robot - People around the robot - Face identification - Sociometric questionnaires	10 -11	70	- Static cameras (RGB) and face identification software Omeron, OKAO vision 3 - Microsoft Kinect, depth sensor	Extracting information from children's classroom behaviour to estimate social status.	Estimated children's social status (71.4% accuracy), position tracking (93.4% accuracy) and identification (65.5% accuracy).
Nasri et al., 2022	Netherlands	Observational	- Children location - Face-to-face contact - Spatial activity level - Video observations	5 -15	150	- i-gotU GT-120 USB, wearables, GPS - OpenBeacon, wearables and static sensors, RFID - MMR sensor, wearables	Examining schoolyards to identify obstacles that can hinder social participation.	Development of a novel sensor data-driven approach that integrates data and differentiate between physical, social, and cultural affordances.

Table 2 - Studies analysing interaction as a predictor of diseases' spread and vocabulary expansion.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Hansen et al., 2019	USA	Observational - Descriptive	- Duration and quantity of child-to-adult and child-to-child conversations - Conversational turn-takings - Location tracking	2.5 - 5	33	- LENA, wearables audio recorders - Ubisense, wearables and static sensors UWB - Support vector machine - Threshold-optimized speech activity detector	Studying children's communication, identifying conversation-promoting activities, and introducing a new method to track children.	Children spent different amounts of time vocalizing in different activity areas.
Leoni et al, 2022	Italy	Observational	- Proximity detection - Face to face interactions	6 - 14	43	- Janus system, wearables, BLE and UWB	Improving the understanding of close proximity interactions between children and educators at summer camps in Italy during the COVID-19 pandemic.	Assessed educator-child and child-child social interactions during the pandemic confirmed the effectiveness of the social bubble strategy in summer camps.
Perry et al., 2018	USA	Observational - Descriptive	- Teacher report of vocabulary expressed - Children vocal interaction - Conversational turn-takings	2 - 3	13	- LENA, wearables audio recorders	Examining the relation between individual language input, children's language use and vocabulary development in a early intervention classroom over a year.	Structured activities were associated with an increase in vocalizations, and children who vocalized more received more input from peers. Children who engaged in more conversational turns showed faster vocabulary growth.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Perry et al., 2022	USA	Observational - Descriptive	- Preschool language scales (PLS-5) - Social contact - Rate of children's vocalisation	2.5 - 3.5	29	- Ubisense, wearables and static sensors, RFID - LENA, wearables audio recorders	Studying the impact of peer vocalisations on language development in inclusive classrooms for children with and without hearing loss.	Social contact and vocalisation rates were different based on hearing status. Children with higher peer vocalisation had better end-of-year language abilities.
Stehlé et al., 2011	France	Observational	- Number of recorded contact events - Time spent in contact	6 - 12	232	- OpenBeacon, wearables and static sensors, RFID	Studying children's interaction patterns in schools to quantify the potential for respiratory infection transmission.	Each child interacted on average with 47 peers through 323 daily contacts. Children spent three times more time with classmates than others. An exposure matrix was determined to inform mathematical modelling.

Table 3 - Studies scrutinizing children's social dynamics.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Banarjee et al., 2023	USA	Observational	- Proximity interaction and orientation - Duration and numbers of interactions	M = 48.26 months, with an SD = 7.47 months	77	- Ubisense, wearables and static sensors, UWB and RFID	Investigating homophily by using social movement and quantifying it in children with developmental disabilities and typical development.	Peers with similar developmental stages had faster approach speeds and longer engagement times. Children with developmental delays were approached with less velocity and had shorter interactions than typically developing peers.
Cocco et al., 2022	Italy	Experimental	- The physical distance between participants and a child with a disability during a five-minute interaction	6 - 9.75	122	- Microsoft Kinect, static camera	Assessing the effectiveness of imagined contact intervention in improving attitudes and behaviour towards disabled children.	Imagined contact improved outgroup attitudes and behaviour among high-status children but not among low-status children.
Fasano et al., 2021	USA	Observational	- Children vocal interaction - Proximity interaction and orientation (social contact)	3 - 6	56	- LENA, wearables audio recorders - Ubisense, wearables and static sensors, UWB	Assessing how children's verbal interactions with peers relate to language skills, focusing on children with autism and their classmates.	Peers' vocalisations influenced vocal responses to peers. Children with autism were more affected by peer input than those with developmental delays.
Iacopini et al., 2023	France	Observational	- Proximity interactions - Duration of interactions - Presence of isolated participants	3 - 6	174	- Wearables wireless proximity sensors RFID	Examining traces of group dynamics derived from proximity data across various social and temporal settings.	Despite differences in age, contexts, and data collection methods, similar group dynamics were observed.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Irvin et al., 2021	USA	Observational – Descriptive	- Children location - Children vocalization - Demographic survey - Survey for teachers about friendship and playmates	3	3	- Ubisense, wearables and static sensors, UWB - LENA, wearables audio recorder Combined speech-activity detection algorithm	Studying friendship dynamics in young children in inclusive classrooms, focusing on proximity and speech interactions of at-risk children.	Children at disability risk and their playmates engaged in vocalisation near each other in different areas.
Messinger et al., 2019	Germany	Observational	- Children location - Movement velocity - Location distribution - Social contact radius	5	16	- Ubisense, wearables and static sensors, RFID	Demonstrating how automated, location-based analysis can effectively offer fresh perspectives on interactions within classrooms.	Confirmed existing research on gender differences in preschool. Provided new insights into how children use space and interact socially with peers.
Nasri et al., 2023	Netherlands	Observational - Descriptive	- Proximity of nodes in a graph considering both temporal and spatial characteristics - Proximity data - Location of the interaction	4 - 12	32	- Wearable proximity tags and static sensors, BT - i-gotU GT-120 USB, wearables, GPS	Using wearable sensors to infer social networks from individual behaviours and introducing a new metric for analysing human behaviour dynamics with time and space.	Children were more accessible to peers within their groups; physical space and play structures influenced interaction patterns and clustering.
Stehlé et al., 2013	France	Observational	- Number of recorded contact events - Time spent in contact	6 - 12	227	- OpenBeacon, wearables and static sensors, RFID	Assessing homophily behaviours related to gender using sensor data on face-to-face interactions.	Gender homophily was prevalent across all primary school grades, more pronounced in boys, especially in 4th and 5th grades, and increased with age.

AUTHORS (YEAR)	COUNTRY	STUDY TYPE	DEPENDENT Or OBSERVED VARIABLES	CHILD AGE	SAMPLE	AUTOMATIC TOOL FOR DATA COLLECTION	AIM	MAIN RESULTS
Veiga et al., 2017	Portugal	Observational	- Strengths and difficulties questionnaire - Children's play behaviour - Peer interactions	4 - 6	73	- OpenBeacon, wearables and central device, RFID	Studying if a specific category of social play holds greater significance in shaping children's social competence compared to other forms of play.	Exercise play was linked to higher social competence, while fantasy play had no association. Smaller peer groups and more extended interactions improved social competence.

The study by Stehlè et al. (2011) recorded data on face-to-face interaction in French primary schools, mapping them into an aggregated network of contacts where nodes represent children and edges represent interaction longer than 2 minutes. Iacopini et al. (2023) analysed group dynamics with new data-driven models, finding similar patterns despite variations in age, context, and data collection methods. Taken together, these studies suggest that employing SNA in education is feasible and potentially beneficial. While the large quantity of data extracted by sensor devices may require complex data analysis, researchers and professionals in education can appreciate the history of interactions recorded by sensors. Indeed, can graphically represent the dynamics between children while preserving informative characteristics such as centrality and density, as it allows to calculate both group indices and individual indices. This relatively innovative approach provides a clearer lens to examine the complexities of child development and socialisation. Moreover, sensor devices can capture the duration of conversations and the approximate distance between individuals to help evaluate the quality of relations in the classroom or the effectiveness of educational interventions. Among those scrutinized in the present review, only one was experimental and implemented an intervention in this direction. In this sense, more research is needed to verify the possibility of using sensor devices to evaluate the effectiveness of educational interventions.

In conclusion, this systematic review reveals that sensor technologies collect data precisely and objectively, but need a strict validation process. SNA can effectively visualise complex social interactions from sensor data, yet its complexity might limit accessibility to non-experts. Lastly, the ecological application of sensor technologies is still scant and highlights the need for accessibility improvements in educational contexts.

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