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Leveraging social network analysis in education through social robots: A review

Panagiota-Ioulia Ntomora * and Kyriakos Petrakos

Department of Pedagogy and Primary Education, School of Education, University of Athens, Greece.

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Abstract

In recent years, there has been a growing interest in the integration of social robots into educational settings, marking a shift in traditional teaching methodologies. This article delves into the implications of incorporating social robots in educational fields investigating particularly how their usage in such settings can be supported by recent advances in the field of Social Network Analysis (SNA). The collective findings from diverse studies underscore the multifaceted benefits of social robots in education. From personalized learning experiences and the development of tutoring skills to continuous assistance, empathic interactions, and specific case studies, social robots have showcased their potential to revolutionize education across various domains. As research in this field continues to advance, the integration of social robots in educational settings holds the promise of fostering inclusive, engaging, and effective learning environments for students of all backgrounds and abilities. Furthermore, Social Network Analysis (SNA) has gained prominence in educational research due to its ability to unveil intricate patterns of interactions among students, educators, and learning resources. The second part of this study provides a comprehensive review of the application of social network analysis in education, focusing particularly on the emerging integration of social robots in this domain. By examining recent literature, this review elucidates the potential of social robots to enhance data collection, interaction analysis, and intervention strategies within educational networks. Italso discusses challenges and future directions for leveraging social robots through social net-work analysis in educational environments.

Keywords: Social Robots; Social Drones; Education; Sociology; Human-Robot Interaction; Personalized Learning; Socio-Emotional Development

1. Introduction

This article aims to provide insights into the dynamic relationship between applied social network analytics and the growing presence of social robots in educational environments. Social robots can be used in education as tutors or peer learners. They have been shown to be effective at increasing cognitive and affective outcomes and have achieved outcomes similar to those of human tutoring on restricted tasks. This is largely because of their physical presence, which traditional learning technologies lack (Belpaeme et al., 2018).

2. Literature review

2.1. A new Era in Education with the emerging technologies

The new Era in Education with the use of Epistemology, along with STEM, Robotics, Games, Virtual Reality and other emerging technologies, has open new views and approximations to the educational practices including assessment, intervention and inclusion for all. The exploitation into educational procedures of new epistemological views [34-39], of Mobiles [25-26] STEM and Robotics [27-28], as well as of Virtual reality and Games [29-33], offers new solutions and

* Corresponding author: Panagiota-Ioulia Ntomora

important improvements to every aspect of educational domain. Among all these the Social networks and Social Robots keeps a central role.

2.2. Social Robots and Education

Researchers (Belpaeme et al., 2018; Kory-Westlund et al., 2019) have extensively explored the impact of social robots on student engagement, personalized learning experiences, and socio-emotional development. Studies suggest that the integration of social robots in class-rooms can enhance student interaction, providing a unique avenue for personalized learning and skill development. The study of Belpaeme et al. (2018) sheds light on the capacity of social robots to provide personalized learning experiences. Their review emphasizes the adaptability of these robots to cater to individual learning styles, creating an environment conducive to better comprehension and engagement. This individualized approach has the potential to revolutionize traditional teaching methods. Vrochidou et al. (2018) present a case study that specifically focuses on the NAO robot's role as a self-regulating didactic mediator. Their work investigates the application of the NAO robot in teach-ing and learning numeracy. The findings highlight the robot's adaptability and effectiveness in supporting educational activities, showcasing the potential for social robots to serve as valuable tools in didactic contexts.

Vagnetti et al. (2015) and Anzalone et al. (2019) contribute to the discussion by exploring the applications of social robots in advanced autism therapy. Their studies demonstrate the positive impact of social robots on children with autism spectrum disorders, showcasing the potential for these robots to facilitate social interactions and skill development. In the same line of thought, Anderson et al. (2016) present a novel approach in the form of a social network system for early autism risk assessment. By leveraging social robots, they aim to identify early signs of autism, paving the way for timely intervention and support. Yang et al.(2023) conducted a study on social interactive behaviors in 24 children with autism using the NAO robot. The study examined behaviors such as proximity, contact, imitation, gaze fixation frequency, gaze fixation duration, and skin conductance response. The experimental activities included greeting, finger pointing, and gaze following. The findings revealed that children with autism exhibited a stronger inclination and preference for interaction with the NAO robot. Skin conductance analysis showed that the rate of change in skin conductance was higher during interaction with the robot compared to human therapists. The children displayed positive emotions, pleasant expressions, and behaviors, and the robot was able to induce active social behaviors in children with autism. Rakhymbayava et al. (2021) conducted a 21-day, one-on-one human-robot social skills intervention training using the NAO robot with 11 children aged 4 to 11 with ASD in a rehabilitation center. They observed the children's engagement, efficacy scores, and duration of inter-action. The results showed that the sustained engagement of children with ASD with the robot remained relatively high even after an extend-ed period of time. Familiarity with the environment and activities increased overall engagement for each child. RoboKind's robots have been specifically designed for autism intervention. These robots engage students in interactive lessons focusing on social skills, emotions, and communication, providing a structured and consistent learning environment (Anderson et al., 2016).According to Nazari et al. (2023) re-search, playful interactions with QTrobot for autism help to perform a more accurate assessment of the child's receptive vocabulary. The results also suggest that QTrobot for autism supports autistic children in receptive language learning.

According to Johan et al., (2022) several forms of social robots have been explored to engage and assist students in the classroom environment, from full-bodied humanoid robots to tabletop robot companions, but flying robots have been left unexplored in this context. In their study, they present seven online remote workshops conducted with 20 participants to investigate the application area of Education in the Human-Drone Interaction domain. The results revealed several design implications for the roles and capabilities of a social drone, in addition to promising research directions for the development and design in the novel area of drones in education.

2.3. Leveraging Social Network Analysis in Education

In recent years, Social Network Analysis (SNA) has emerged as a potent methodology for understanding the intricate dynamics of educational environments, especially with the widespread influence of social networks. The integration of social robots into educational settings has fur-the revolutionized SNA practices by enabling real-time interaction monitoring and intervention (Belpaeme et al., 2018). Grunspan et al. (2018) utilized SNA to investigate the formation and effectiveness of study groups in university settings, while Cela et al. (2015) explored the impact of social interactions on student engagement in online learning environments. Traditionally, sociograms have been employed in educational settings to understand social dynamics, communication patterns, and power struggles within classrooms (Leung et al., 2006). However, the advent of social robots equipped with sensors and artificial intelligence algorithms has facilitated real-time data collection and analysis. For instance, Belpaeme et al. (2018) demonstrated how social robots deployed in classrooms could monitor peer interactions and identify students at risk of social isolation.

Samanta et al. (2020) highlighted the importance of using graph theory and network relationships to comprehend social structures within classroom settings. The application of SNA in education spans various areas, including the study of student behavior, learning outcomes, edunational policies, and organizational dynamics (Samanta et al., 2020). Understanding basic SNA concepts such as nodes, edges, centrality, and group cohesion is crucial for analyzing social interactions in educational contexts. Samanta et al. (2020) proposed a three-stage architecture for implementing SNA in educational research, encompassing relationship building, data analysis, and outcome comparison. Moreover, SNA holds significant promise for informing educational policies, enhancing pedagogical practices, and fostering equitable learning environments (Grunspan et al., 2017). By unraveling the structural and relational aspects of educational environments, SNA provides researchers with essential tools to investigate diverse phenomena, ranging from collaborative learning patterns to teacher-student dynamics. Furthermore, re-cent studies have explored the application of SNA in special education leadership, emphasizing the importance of collaboration, social interaction, and distributed leadership in promoting effective problem-solving and knowledge exchange within organizations (Mering, 2017).

Lim (2023) provided valuable insights into how SNA can be applied to analyze student interactions on online discussion boards and its relation to learning outcomes. The study highlighted the importance of promoting social presence and monitoring interaction patterns in online learning environments. Overall, SNA offers a powerful lens for understanding and improving educational practices in diverse contexts.

2.4. Benefits of using social robots as tutors

Although progress has been made in constituent technologies of robot tutors—from perception to action selection and production of behaviors that promote learning—the integration of these technologies and balancing their use to elicit student social behavior and consistent learning still remain open challenges. Human tutors still provide a gold standard benchmark for tutoring interactions of robotic tutors. Trained human tutors are able to adapt to learner needs and modify strategies to maximize learning. Comparisons between robots and humans are rare in the literature, so no meta-analysis data were available to compare the cognitive learning effect size (Belpaeme et al., 2018). According to Senft et al(2019),robots should remain tools in the hands of the teachers, and teachers should have the freedom to shape the robot into their own personalized teaching assistant. The heart of the thesis lies in fostering teacher autonomy. Equipped with advanced artificial intelligence, social robots simulate human-like interactions, creating a more dynamic and interactive learning environment. This facilitates improved communication between the robot tutor and the student, ultimately enhancing the learning experience. Unlike human tutors, social robots offer round-the-clock assistance, ensuring students have access to support and guidance whenever needed. This feature contributes to a more effective and efficient learning process. Social robots show promise in assisting students with learning disabilities by adapting learning materials to cater to diverse needs. This adaptability helps students with varying requirements grasp and retain information more effectively (Belpaeme et al., 2018, Senft et al. 2019).

2.5. Ethical issues and challenges

While social robots as tutors offer the potential to revolutionize education by providing personalized, interactive, and continuous learning experiences, ethical implications demand careful consideration. As this technology evolves, collaborative efforts involving educators, policy-makers, and society are essential to establish guidelines ensuring the responsible and ethical integration of social robots in educational set-tings. The utilization of social robots in educational settings raises privacy concerns, as these robots collect data on students' learning pat-terns and behaviors. Ethical guidelines regarding data storage, access, and usage are imperative to safeguard students' privacy. The potential for emotional bonding between students and social robots presents ethical questions. While some argue that such bonds enhance the learning experience, concerns exist about the emotional dependency students might develop on these machines. The integration of social robots as tutors may lead to concerns about job displacement for human educators. Balancing technological advancements with the preservation of the invaluable human touch in education is essential to address this ethical dilemma (Leite et al., 2018).

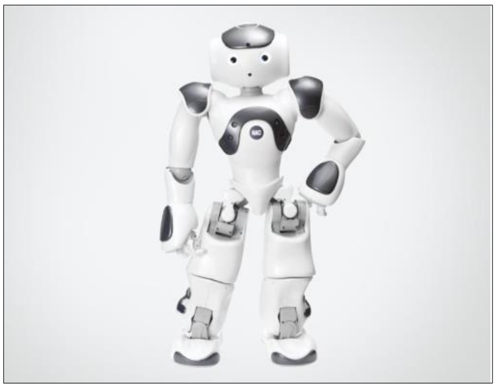
2.6. Use of social robots in education

Social robots have indeed been employed in various educational settings, showcasing their potential to revolutionize traditional learning methods. Research and pilot programs around the world have explored the integration of social robots as educational tools, offering insights into their impact on student engagement, learning outcomes, and overall educational experiences. Social robots have been utilized as class-room assistants to enhance engagement and interaction. For instance, studies have shown that robots can assist teachers in managing class-rooms, providing support for repetitive tasks, and even helping students with individualized learning plans (Belpaeme et al., 2018). In the same study, Belpaeme et al.(2018) highlight the benefits of having a physically embodied social robot that has a tutoring role in a classroom. One of the benefits is the ability to foster engagement, creating a positive learning experience for students. In addition, the same review underlies the fact that Human-Robotics Interaction (HRI) literature used a wide variety of robot appearances; pointing out that almost all of them had social attributes and features (i.e. humanoid features such as head, eyes, mouth, arms or legs). Moreover, in another review on robots used in education, Mubin et al.(2013) showed that the role of a classroom robot is generally seen as an assistant or a tutor supporting the teacher and students. To this end, literature reviews suggest that social robots in education are likely to be autonomous in their movements and will depict an assistant to a teacher role in a classroom environment (Belpaeme et al., 2018, Mubin et al., 2013).

According to Yang et al. (2023), by integrating methods such as Applied Behavior Analysis, Structured Teaching, and The Social Motivation Theory commonly employed for children with autism, the curriculum of a special education school can be structurally re-designed, and pilot experiments can be conducted to explore the effectiveness of social robots in the classrooms of children with Autism spectrum disorder (ASD) and their classroom performance. This analysis aims to uncover the potential application of social robots in the classrooms of children with ASD. Moreover, based on existing literature, social robots have already been extensively practiced in classrooms with typically developing children. In the future, social robots may serve as effective mediators in classrooms for both typically developing children and children with autism, promoting the development of inclusive education (Yang et al., 2023).

2.7. NAO Robot in Inclusive Education

Among the various robots utilized for educational purposes, the NAO humanoid, developed by Aldebaran Robotics (now owned by SoftBank Robotics as of April 2024), has gained significant attention.



https://www.softbankrobotics.com/solution/#anc-01. Retrieved on 4 April 2024

Figure 1 NAO Humanoid: SoftBank, 2024

NAO has been utilized among others in inclusive education settings to assist students with autism spectrum disorders. The robot engages students in social interactions, supports communication development, and helps in fostering social skills. As it is mentioned to the research of Vrochidou et. al (2018), the social robot NAO was used to execute a specific educational activity in a structured school environment. The robot acted as a mediator to co-teach a no robotic related subject to elementary school students. The proposed activity was specially de-signed for K-12 educational curriculum in-line with modern pedagogical theory of learning. Pilot results are encouraging: Students were motivated by the presence of the robot and displayed a better understanding of the mathematical concepts taught. There are a number of significant considerations regarding the scope of the conducted research. First, the robot coaching session was limited to only a single interaction. Obviously, a long-term study, would measure more precisely the educational effectiveness of the robot tutor. Although NAO is a social robot, only some of the characteristics recommended for effective learning were implemented. Further research on characteristics such as role model, nonverbal feedback, attention building, empathy, communication and collaboration, is needed. As the field of robotics advances and more powerful and adaptive robotic technologies emerge, the autonomy of the robot will be increased. In particular, future work includes more sophisticated planning strategies on NAO, e.g. mechanisms to help the robot decide how to proceed with the educational activities (So et al., 2023).

2.8. QTRobot

QTrobot has been employed as an intervention tool for children with autism spectrum disorders to enhance social skills. The robot provides personalized social stories and interactive lessons, contributing to improved social interactions among students. QTrobot has the ability to demonstrate differentiated facial expressions. According to Nazari et al.,

(2023) the results of exploratory analysis show that playful interactions with QTrobot for autism help to perform a more accurate assessment of the child's receptive vocabulary. The results also suggest that QTrobot for autism supports autistic children in receptive language learning. Data collected by the robot from sessions with children and customer feedback videos have shown that even parents without technical backgrounds can easily utilize the robot at home to provide structured interventions and support their child's development. Beyond its educational role, parents have reported that QTrobot indirectly enhances their knowledge of their child's developmental progress and increases their understanding of evidence-based interventions for receptive language skills. By observing their child's performance in each task and witnessing how the robot delivers simple instructions, reinforcement, and structured prompts, parents gain valuable insights. Consequently, QTrobot empowers parents, enabling them to reliably participate as proxies in assessments by better understanding their child's strengths and needs. Additionally, QTrobot provides reporting and progress monitoring features, capturing data on task performance and maintaining a record of each child's progress. This data serves as a reliable source for objective evaluation, such as assessing a child's receptive language repertoire. Professionals and speech therapists can use this information to accurately evaluate a child for individually tailored interventions. Even though that the robot is still (as of 2024) expensive, it is far more affordable and accessible solution than speech therapy and it can bring several added benefits including improving parents ability to teach speech/communication skills, developing a better understanding of the child's ability and perform better as a proxy, and as a consequence, minimizing inaccurate resource allocation caused by imprecise evaluation for the child (Nazari et al., 2023).

Figure 2 QTRobot [14]

2.9. Social Drones in Education

According to Johal et al., (2022) the application domain of social drones (or flying social robots) in education is a vast and promising research field, not yet thoroughly investigated. They state that flying social robots provide an opportunity to explore the design space and implications of drones in an educational context, in particular looking at drones that support the classroom environment, but with no intention – at least for the time being - of replacing the teacher (Johal et at., 2022).

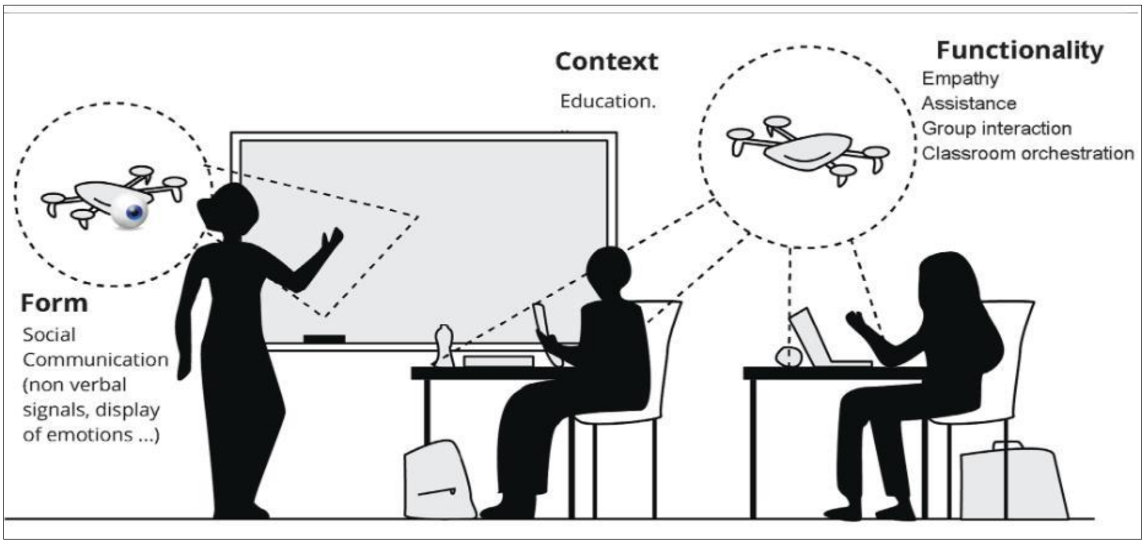


Figure 3 An illustration of social drones in a classroom, with examples of instantiating the social form and social function in an educational context [17]

After running a series of seven online design workshops (20 participants) with the support of a sketch artist, Johal et al., (2022) analyzed, discussed, and extracted several main design implications that can advance future research on social drones in education, namely:

- A teaching assistant and a butler are the main social roles in the context of designing a social drone in educational settings .While the roles that came out from the workshops were relatively similar to other social robots in education (e.g. Belpaeme et al., 2018) the findings pertaining to tasks and abilities differed. In particular, it was found that the abilities for the drone to easily move in the classroom made participants think of different scenarios: handing sheets of paper, roaming in the classroom to address students' questions, and acting as a carrier page onto carry messages between students. Another main identified role was that of the class-room butler. As discussed in the paper, while common for home robots, this role has not been explored in the classroom context.
- A social drone in education should have several interaction modalities to sense the user's behavior, particularly the non-verbal behaviors exhibited by the user. In addition, the drone should also have the capabilities to sense its surrounding environment. These are mostly considered as input channels for the drone to make sense of its users and environment and adapt to these.
- A social drone in education should also be able to exhibit and communicate via different interaction modalities. In particular, the drone should have expressive embodied motions as an output channel.
- Social Drones could benefit from an adaptive design of their appearance and role. For example, different illuminating body colors could be customized to mean different roles in educational settings.

3. Social network analysis in the educational context

In recent years, and partly due to the extensive evolution and impact of Social Networks, Social Network Analysis (SNA) has emerged as a powerful tool for understanding the complex dynamics of educational environments. By mapping social relationships among students, educators, and resources, SNA offers insights into information flow, knowledge sharing, and collaborative learning processes. Moreover, the integration of social robots into educational settings has opened new avenues for conducting SNA by enabling real-time interaction monitoring and intervention. Our aim is to explore the body of recent research that analyzes the application of SNA in education and the evolving role of social robots in facilitating this analysis. SNA provides a quantitative framework for studying social structures within educational contexts. Studies have employed SNA to analyze various aspects of educational systems, including peer influence, knowledge diffusion, and academic performance. For instance, Grunspan et al. (2018) utilized SNA to examine the formation of study groups in a university setting and identified key factors influencing their effectiveness. Similarly, Cela et al. (2015) applied SNA to investigate the impact of social interactions on student engagement in online learning environments.

SNA practices have long been used in educational settings with a common notable example the constructions of Sociograms (Leung et al., 2006) that help educators grasp the social dynamics, lack of communication and power struggles within a classroom. The emergence of social robots has revolutionized data collection and analysis techniques in educational research. Social robots equipped with sensors and artificial intelligence algorithms can capture real-time interaction data, including verbal and non-verbal cues. By embedding social robots within educational settings, researchers can observe social dynamics and communication patterns with unprecedented accuracy. For example, Belpaeme et al (2018) have demonstrated how deploying a social robot in a classroom could help monitoring peer interactions and identify students at risk of social isolation.

Samanta et al. (2020) emphasized the significance of understanding social structures using graph theory and network relationships, particularly within classroom settings. SNA as a practice in educational environments involves analyzing the relationships between nodes (individuals or entities) and edges (links or connections) in a network, with a focus on classrooms and interactions among students and teachers. The application of SNA in education encompasses various areas such as studying student behavior, learning outcomes, educational policies, and organizational dynamics. Samanta et al. (2020) delve into the use of social media in education, emphasizing its role in facilitating communication and collaboration among educational institutions and learners. They discuss the importance of understanding basic terms and concepts associated with SNA in the light of the social interactions in a classroom, namely the notions of nodes, edges, centrality, and group cohesion.

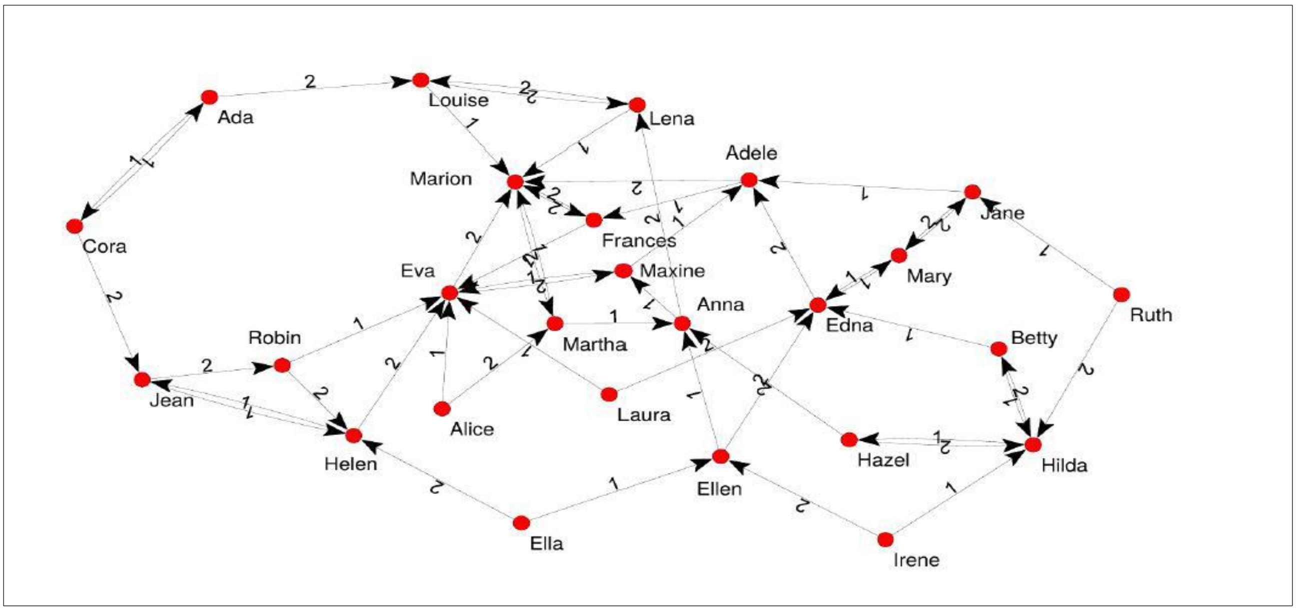


Figure 4 A graph representing a girls' school dormitory dining-table partners, *1st and 2nd choices (Moreno, The sociometry reader, 1960). Nodes are students, an edge from node A to node B indicates that girl B is a dining table partner choice for girl A. The number of each edge represents the number of times girl A has chosen girl B as a dining partner*

They describe a three-stage architecture for implementing SNA in educational research, including building relations, analyzing data, and comparing outcomes. Additionally, they explore the results of applying SNA in education, discussing findings from mid-term assessments and improvements observed in student interactions, teacher-student relationships, and group dynamics. The role of data mining in educational research is also mentioned, with a highlight on its potential to extract valuable insights from educational data and inform teaching and learning practices.

Grunspan et al. (2017) elucidate the intricate interplay between nodes (individuals or entities) and edges (relationships) within educational networks, particularly focusing on classroom dynamics. They highlight the significance of SNA in unraveling the structural and relational aspects of educational environments, offering a nuanced understanding of student interactions, learning behaviors, and knowledge dissemination processes. By discussing methodological approaches, theoretical frameworks, and practical applications of SNA in education, the paper equips researchers with essential tools to investigate diverse educational phenomena, ranging from collaborative learning patterns to teacher-student dynamics. Furthermore, it underscores the potential of SNA to inform educational policies, enhance pedagogical practices, and foster equitable learning environments.

4. Social Network Analysis in Special Education

Mering (2017) conducted a comprehensive study that examines the dynamics of social networks within educational settings, particularly focusing on special education leadership and its impact on collaboration, knowledge exchange, and school performance. The study is grounded in the principles of distributed leadership, social network analysis (SNA), and diffusion of knowledge. These theories emphasize the importance of collaboration, social interaction, and relationship building in promoting effective problem-solving and knowledge exchange within organizations. SNA is employed as the primary methodological approach to analyze the structural dimensions of advice-giving and receiving networks within two elementary schools. The study investigates network properties such as density, reciprocity, and centrality to understand the relationships between leadership distribution, knowledge exchange, and school performance. The findings suggest that de-centralized networks with high reciprocity tend to facilitate effective collaboration, knowledge sharing, and potentially improved school performance. Strong ties and reciprocity within networks were observed, but the study also revealed discrepancies between the type of advice exchanged and its impact on knowledge enhancement. The study underscores the importance of fostering collaborative environments and distributing leadership within schools. It suggests that leaders should prioritize building shared vision, scheduling time for collaboration, and addressing common issues collectively to enhance information flow and knowledge dissemination among staff members.

Boruzie et al. (2022) suggest that although Social Network Analysis has been previously used for collaborative learning purposes such as group assignments and study groups, SNA practices have not been formally integrated into the standard school curriculum. The study recommends future research to assess user satisfaction and challenges associated with SN usage for collaborative learning and suggests integrating SNs into teaching and learning through strategies like gamification.

5. Social Presence’s Impact on Learning Outcomes

Lim (2023) provided valuable insights into how student interactions on online discussion boards can be analyzed using Social Network Analysis (SNA) and how these interactions relate to learning outcomes. The study collected data from archived student discussion threads and an online survey. The discussion threads were analyzed to determine who interacted with whom, and adjacency matrices were created. The survey assessed students' perceptions of social presence, learning achievement, and course satisfaction using established frameworks and scales. SNA was then used to analyze the properties and structural patterns of students' interactions. Measures such as out degree and in degree centrality were calculated to identify the extent of outgoing activity and incoming interactions for each student. Other metrics like density, reciprocity, and centralization were also analyzed to understand the overall structure of the discussion networks.

The study found that specific students tended to maintain high levels of out degree centrality throughout the course, indicating consistent participation. However, there was more variability in in degree centrality rankings. The analysis also revealed insights into changes in density, reciprocity, and centralization over time. Additionally, correlation and mediation analyses showed significant relationships between interaction measures, social presence, and learning outcomes. These findings suggest that students' interaction patterns can influence their perceived learning achievement and satisfaction. Social presence emerged as a key mediator between interaction measures and learning out-comes, highlighting its importance in online learning environments. The study also discussed implications for instructors and instructional designers, emphasizing the need to promote social presence and monitor interaction patterns.

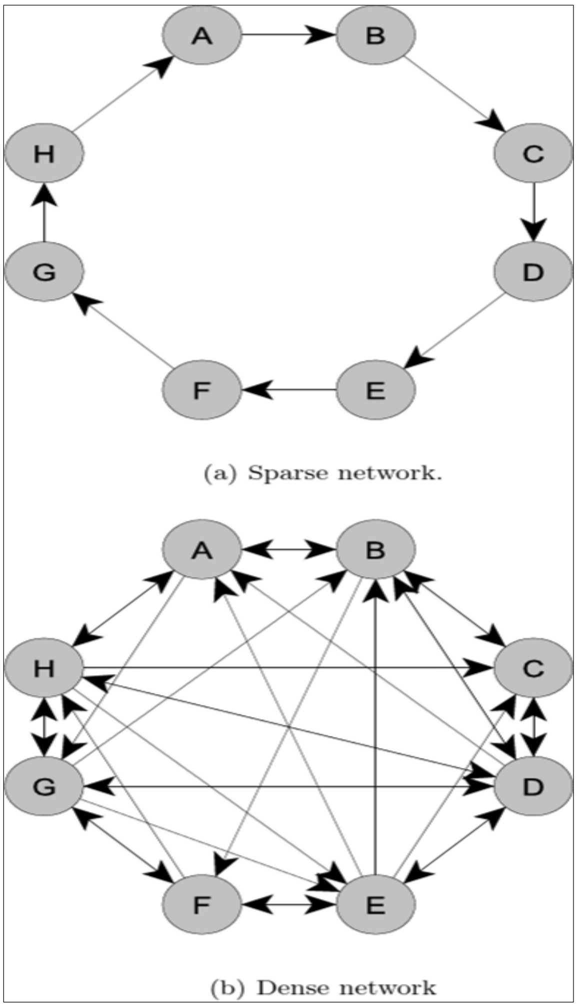


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Figure 5 Levels of Density in a social network

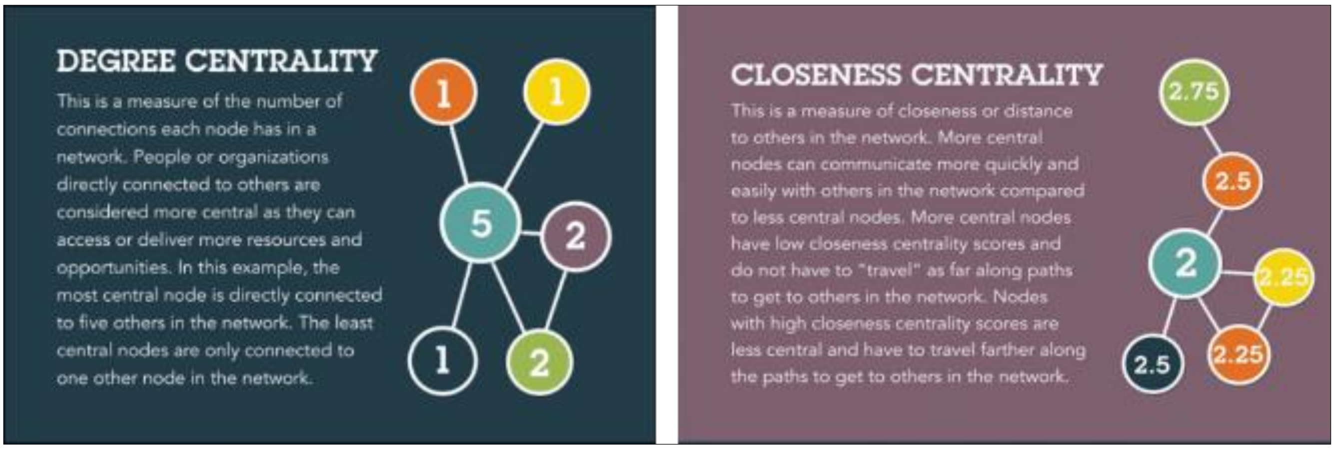

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Figure 6 Types of Network Centrality (Degree and Closeness)

6. Conclusion

The integration of social robots in SNA offers several benefits, including enhanced data granularity, automation of data collection, and real-time feedback generation. Moreover, social robots can facilitate interventions by providing personalized assistance and support to learners. However, challenges such as privacy concerns, technical limitations, and ethical considerations need to be addressed to ensure the responsible use of social robots in educational research. The use of social robots in SNA opens up new avenues for research and innovation in education. Future studies could explore the potential of social robots in facilitating collaborative learning, promoting social-emotional development, and fostering inclusive educational environments. Moreover, interdisciplinary collaborations between researchers in education, robotics, and computer science can drive advancements in social robot design and functionality for educational applications.

Combining the use of social robots and social network analysis holds great promise for advancing our understanding of educational systems and improving learning outcomes. By leveraging the capabilities of social robots, researchers can gain deeper insights into social interactions, network structures, and learning processes. However, careful consideration of ethical, technical, and methodological issues is essential to harness the full potential of social robots in educational research.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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