

Visualization of Physical Education Classroom Interaction Structure and Teaching Improvement Path Based on Social Network Analysis

Yong Wang¹, Li Zhu², and Mingbang Li³

¹Department of Physical Education, Sichuan University of Media and Communications, Chengdu 611745, Sichuan, China

²The Sports School, Sichuan Technology and Business University, Chengdu 610000, Sichuan, China

³College of Physical Education and Health, Geely University of China, Chengdu 610000, Sichuan, China

Corresponding author: Li Zhu (e-mail: 13880638777@163.com)

ABSTRACT Existing studies on classroom teaching often focus on unilateral evaluation of teacher behavior or student performance, while insufficient attention is paid to the interaction structure that supports technical skill acquisition. To address this limitation, this study uses social network analysis to visualize and quantify classroom interaction in an 8-hour middle school basketball teaching unit. A total of 1027 interaction events among one teacher and 40 students were collected through non-participant observation and video recording, and a directed weighted adjacency matrix was constructed. UCINET was used to analyze the overall network, cohesive subgroups, and individual centrality. The results show that the interaction network has a low-density (0.28) and high-centrality (0.52) core-periphery structure, with the teacher and several high-skill students occupying central positions. Four homogeneous subgroups based on skill level and gender were identified, and peripheral isolated students showed significantly fewer interaction opportunities. The study proposes teaching improvement paths based on group restructuring and interaction redistribution. The method also provides an engineering-education reference for technical classrooms that use wireless sensing, video analytics, or antenna-supported data capture to monitor learning interaction structures.

INDEX TERMS social network analysis, classroom interaction, engineering education, wireless sensing, visualization

I. INTRODUCTION

THE digital wave and shifting teaching paradigms are radically transforming physical education. The main line of the current research concerns the given teaching styles and behavioral approaches of teachers or the analysis of the motor skills and performance of the students. Although these types of studies are useful, they tend to separate instruction and learning as two rather unrelated aspects. The physical education classroom is nothing but an active social network of teachers and students, or students themselves. The interaction relationship scheme in it such as people interact with whom, frequency and intensity of relation directly impact the information flow, creation of social support and finally teaching effectiveness. Nevertheless, current quantitative studies and visual data on the bulk shape, major features, and ways of creating this micro-social organization is not enough. The question of how correctly to see through the complicated network of classroom interactions and on this basis to diagnose and optimally teach, has become an important and urgent problem to

the improvement in the quality of physical education. The significance of the given paper consists in the fact that it is the first to apply the Social Network Analysis (SNA) to the analysis of interactive relationships in classrooms of physical education to be able to quantitatively describe and visualize the interactive structure. In particular, the given study based on the close classroom observation and data-based coding built a directed weighted interactive network that included teacher and learner nodes and analysed it on three levels: the general structure, subgroup dispersion, and individual location. "Interaction" is defined as observable information exchange behaviors in the classroom with clear initiators and recipients, specifically divided into two categories: (1) resource interaction provided by teachers: mainly referring to teachers' explanations, demonstrations, instructions, guidance, and feedback to students; (2) output interaction of student behavior: mainly referring to students asking questions and responding to teachers, as well as communication, mutual assistance, and collaboration among students. This classification runs through the entire process

of data collection, coding, and subsequent analysis. This lays an empirical bridge between structural diagnosis and teaching intervention, guiding instructors toward scientific corrective actions that align physical education pedagogy with the technical precision required in manufacturing to facilitate interactive equity and profound involvement. By applying these insights, educators can synchronize classroom dynamics with the rigorous operational standards of the industry to ensure more effective skill transmission.

II. RELATED WORK

As the field of physical education continues to respond to digital transformation, teaching paradigm shift and the new normal of education in the post-pandemic era. Murtagh et al. [1] extracted themes and evaluated the effectiveness of online teaching, student and teacher experiences and key influencing factors. Ferraz et al. [2] sorted out the teaching models commonly used in current physical education and explored their future development trends. Global physical education has been forced to shift from face-to-face to virtual environment. González-Calvo et al. [3] revealed the practice, difficulties and adaptive strategies of teachers in virtual teaching. De-kun and Memon [4] used random forest and other algorithms to analyze and realize the automatic evaluation of students' motor skills and sports performance. Tagimaucia et al. [5] focused on instructional design, student participation, assessment methods and teacher roles.

The Spectrum of Teaching Styles is an important theoretical framework that influences teaching practice. Pill et al. [6] sorted out the correlation between the Spectrum of Teaching Styles (from teacher-led to student-led) and different teaching models. Liang and Yin [7] constructed a user-resource trust network and combined collaborative filtering and trust propagation mechanisms to calculate resource recommendation weights in order to achieve personalized and balanced recommendations of sports teaching resources. Lobo [8] revealed students' multidimensional perceptions of online physical education classes, including feedback on the ease of using the technology platform, the adaptability of course content to the online environment, and the quality of interaction with teachers and peers. Liu and Zhuang [9] constructed a data-driven multimedia sports teaching effect evaluation model. Şerbu et al. [10] revealed the relationship between students' subjective feelings in physical education class and the use of fitness equipment, pointing out the possible shortcomings in current physical education teaching. Most research focuses on teachers' behaviors, styles, and strategies, or students' skills and performance assessments. This study, however, collects and analyzes data on interactive relationships in physical education classes and uses social network analysis techniques to visually present the overall topological structure, subgroup distribution, and individual centrality characteristics of classroom interactions. This reveals key teaching contextual factors that influence the interaction structure and ultimately constructs a targeted improvement path based on visual evidence to

enhance classroom participation and teaching effectiveness.

III. METHODS

A. RESEARCH SUBJECTS AND DATA COLLECTION

This study employed a case study approach, selecting a science class in the second year of junior high school in a certain city as the research subject. The class had 40 students, including 22 boys and 18 girls, and was taught by a male physical education teacher with 10 years of teaching experience. This class was chosen as the case study because it can reflect the general situation of middle school physical education classes. This study was approved by the Ethics Committee of Sichuan University of Media and Communications, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form. The research data collection lasted for a complete teaching unit (8 class periods in total, 2 class periods per week), and the teaching content was basic basketball tactics. Data collection mainly adopted the non-participant observation method, supplemented by video recording. In each class, two trained observers were located at the edge of the field and used a pre-designed structured observation record form to record all the targeted interactive events that occurred in the classroom. The recorded interaction types included three categories: (1) verbal interaction: such as teacher explanation, questioning, and feedback, and student questioning, answering, and communication; (2) visual interaction: such as teacher demonstration and student observation and imitation; (3) physical mutual assistance interaction: such as protection and assistance between students and tactical cooperation practice. Each interaction recorded the initiator, receiver, summary of interaction content and duration. In addition, the spatial distribution of students in the classroom was also recorded, such as the physical distance between students and the order of the queue when they were lining up to practice shooting. To ensure the accuracy and consistency of the data, all classes were recorded in their entirety. After the observation, the research team members cross-checked the observation records and video content, and reached a consensus on any doubts through group discussion. In the end, a total of 1,027 valid interaction event records were obtained [11].

B. SOCIAL NETWORK MATRIX CONSTRUCTION AND ANALYSIS METHODS

Transforming the collected interaction records into a relation matrix required for social network analysis is fundamental to the analysis. First, 41 individuals—the teacher and 40 students—are defined as "nodes" in the network. Then, a 41x41 directed weighted adjacency matrix is constructed. Rows in the matrix represent interaction initiators, and columns represent interaction receivers. The value of the matrix element a_{ij} represents the total duration (in seconds) of the interaction event from node i to node j during the observation period. For example, if student A initiates

three interactions with student B, lasting 30 seconds, 45 seconds, and 15 seconds respectively, the value in the corresponding row A and column B of the matrix would be 90 seconds. In subsequent analysis, the matrix weights were modified and decomposed into two dimensions: (1) the basic intensity of the interaction: based on the total duration of the interaction; and (2) the pattern characteristics of the interaction: by calculating the two indicators of "average duration of each interaction" and "interaction frequency", high-weighted connections were classified in a secondary manner. For example, a connection with a total duration of 90 seconds may consist of three 30-second interactions or one 90-second in-depth explanation. This weighting process distinguishes the intensity of interactions and reflects the essence of the interaction more accurately than a simple binary relation (interaction or absence). After obtaining the original matrix, the professional social network analysis software UCINET 6.0 is used to calculate all quantitative indicators, and its built-in NetDraw tool is used to visualize the network graph. The analysis is mainly carried out from three levels: (1) Overall network structure analysis: calculate network density, average path length, network diameter, cohesion index, degree centrality and other indicators to describe the overall compactness, information transmission efficiency and centralization of the network. (2)

Cohesive subgroup analysis: use the iterative correlation convergence method (CONCOR) to perform block model analysis, detect the subgroups with relatively close internal connections in the network, and analyze their member characteristics. (3) Individual centrality analysis: calculate the degree centrality (distinguishing between in-degree and out-degree), intermediate centrality, closeness centrality and other indicators of each node to evaluate the position, influence and mediation ability of each individual in the network [12-13]. Figure 1 shows the in-degree centrality data:

As shown in Figure 1, the simulated data vividly reveals the extreme imbalance in the distribution of interactive resources: teachers (node 1) and a few core students (such as nodes 2 and 3) occupy most of the "attention inflow" (in-degree) in the network, while a large number of students, especially those at the network periphery, have extremely low in-degree centrality. This typical distribution pattern indicates a serious problem of unequal interaction opportunities in real classroom interaction data.

C. FRAMEWORK FOR ANALYSIS OF TEACHING CONTEXT FACTORS

In order to understand the reasons for the formation of the above-mentioned social network structure characteristics, this study set up an analytical framework for teaching context factors. The framework mainly covers three aspects: (1) Teaching organization mode: analyze the main teaching organization forms adopted in the classroom, such as the time proportion of whole-class unified teaching, group practice, individual practice, etc., and their relationship with

the interaction structure. (2) Task structure design: analyze the types of learning tasks set by teachers (such as closed skill practice, open tactical cooperation, game competition, etc.) and their orientation to the needs of interaction. (3) Teacher behavior strategy: focus on analyzing the teacher's classroom positioning and movement trajectory, feedback distribution mode (whether it is directed at individual students, groups or the whole class) and its impact on student interaction. This part of the analysis is mainly based on the qualitative analysis of classroom observation records and videos, aiming to provide an explanatory background for the quantitative network structure characteristics [14]. (4) Physical spatial layout: Analyze the spatial arrangement of students in the classroom (such as fixed queues, free dispersion, etc.) and how physical distance affects the possibility and frequency of interaction.

IV. RESULTS AND DISCUSSION

A. OVERALL NETWORK STRUCTURE CHARACTERISTICS AND THE INFLUENCE OF TEACHING CONTEXT

By calculating the constructed interactive network of the physical education classroom, a series of indicators describing its overall structure were obtained (Table 1). Network density, reflecting the ratio of actual interactions to all possible interactions, was calculated to be 0.28. While teachers do have direct contact with the vast majority of students, this contact is mostly one-way (teacher-to-student). The main reason for the low network density is the scarcity of lateral connections between students. Of the 780 student-student relationships that could potentially form among 40 students, the proportion of observed, sustained student-student relationships is very low. Therefore, although the teacher is a highly connected center, the overall network density remains low due to the lack of inter-student connections, exhibiting a "radial" rather than a "network" structure. This indicates that only 28% of possible interactions were actually observed in this classroom, suggesting a relatively sparse overall level of connectivity and numerous unconnected "structural holes." The network's average path length (APL) was 2.1, and its diameter was 4. APL means that on average, information or influence needs to pass through approximately two intermediaries to be transmitted from one student to another, indicating that the network has a certain information transmission efficiency but is not highly connected. It should be noted that in a relatively simple classroom network dominated by a single teacher, a shorter average path length is expected, reflecting the reality that the teacher acts as a core hub directly connected to the majority of students. Nevertheless, this metric still helps to quantitatively understand the efficiency of information transfer from the core to the periphery. The network's degree centrality potential was 0.52 (after standardization), which is relatively high, indicating a significant power or attention concentration phenomenon in the network, where a few individuals occupy the central positions.

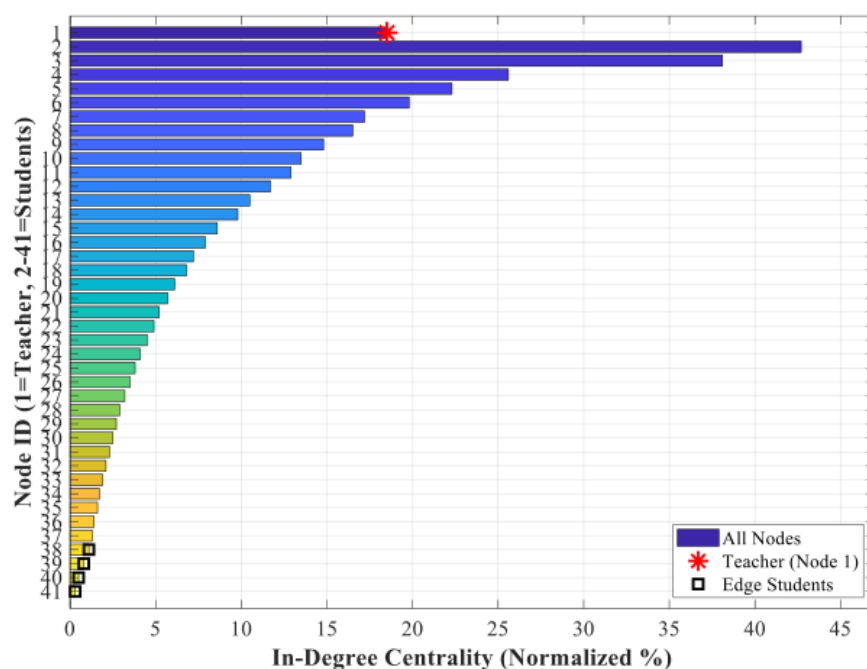


FIGURE 1. shows the in-degree centrality of the midpoints in the physical education classroom interactive network.

TABLE 1. Overall Network Structure Indicators

Indicator Name	Calculation results	Brief explanation of the indicator's meaning
Number of nodes	41	The total number of individuals in the network (1 teacher + 40 students).
Network density	0.28	The proportion of actual interactive relationships to all possible relationships reflects the tightness of the network.
Average path length	2.1	The average of the shortest paths between any two nodes reflects the efficiency of information transmission.
Network diameter	4	The maximum value of the shortest path between any two nodes reflects the network size.
Point-degree central potential	0.52	The degree of network centralization; a higher value indicates a greater concentration of power.

The visualization of the aforementioned quantitative indicators (network diagram) intuitively demonstrates a topological structure approximating a core-periphery configuration. Teacher nodes occupy the absolute core position, maintaining direct and strong connections with the vast majority of students. Student nodes, however, exhibit significant differentiation: a small number of students with exceptional motor skills or extroverted personalities surround the teacher, maintaining numerous connections with the teacher and other classmates; most students are in a semi-peripheral state with limited interaction; and a small number of students with weaker skills or introverted personalities are relegated to the network's periphery, with few connections and the risk of becoming "interaction islands."

The formation of this overall structure is closely related to the observed teaching context. In this case, the teacher primarily adopted a teaching organization model dominated by teacher demonstration and explanation, with students following along in practice. The task structure mainly consisted of uniform, closed skill exercises, such as lining up

to practice shooting basketballs. While this model facilitates classroom management, it objectively limits students' need for autonomous and diverse interaction. The teacher's position was habitually fixed in the center of the field or at the front of the line, and their feedback was mainly focused on students with good skills or those making mistakes. This further reinforced the star-shaped interaction structure centered on the teacher and radiating outwards to a few students, failing to effectively promote lateral, network-like connections among students. Therefore, the uniformity of the teaching organization model and the closed nature of the task structure are the main contextual factors leading to low network density and excessive central power.

B. DISTRIBUTION AND GENETIC ANALYSIS OF CONDENSED SUBGROUPS

Using the CONCOR algorithm to perform subgroup analysis on the network, the 41 nodes were clearly divided into four cohesive subgroups. Subgroup 1 consists of the teacher and 8 students (all male, and key players on the

TABLE 2. Characteristics and Interaction Patterns of Members of Cohesive Subgroups

Subgroup number	Core members	Number of members	Main features	Group interaction intensity	Main objects for connecting to outgroups
Subgroup 1	Teachers, male students A, B, C, etc.	9	Highly skilled, teacher focus	Extremely high	Stronger connection with subgroup 2
Subgroup 2	Boys: D, E, F, etc.; Girls: A, B	12	Highly interested, active member	high	Subgroup 1, Subgroup 3
Subgroup 3	Girls C to P, boys G	15	Predominantly female, with intermediate skills	medium	The connection is relatively weak
Subgroup 4	Boys: H, I, J; Girls: Q, R	5	Weak skills, introverted personality	Extremely low	Almost no connection

class basketball team), with frequent and intense internal interaction. Subgroup 2 contains 12 students (10 boys and 2 girls), mainly students with a high interest in basketball but not members of the school team, with more internal interaction and a strong connection to subgroup 1. Subgroup 3 consists of 15 students (14 girls and 1 boy), with internal interaction mainly among girls, and relatively weak external connections. Subgroup 4 consists of 5 students (3 boys and 2 girls), who have low scores in sports skills tests, are introverted, and interact very little in class, almost isolated. (See Table 2.)

The subgrouping was not random; its boundaries highly overlapped with students' athletic skill levels, gender, and pre-existing friendships. Furthermore, observations revealed that the fixed practice queues in the classroom were also a significant reason for the formation of these subgroups. For example, the girls in subgroup 3 often clustered in the same area while practicing in line. This physical proximity created natural conditions for their internal interaction, which, to some extent, more directly explains why they formed independent interaction circles than the abstract concept of "introversion." This reveals the principle of "homogeneity" in physical education classroom interaction, namely, students tend to interact with those who are close in skill level, gender, or physical space. While this homogeneous clustering can provide social support within a small group, it can also reinforce barriers between groups, leading to increased skill differentiation and hindering the overall development of all students. Particularly in this case, gender differences were a significant factor in subgrouping, with girls almost forming separate groups. This is related to the generally perceived "masculine" nature of basketball and the failure of task design to adequately consider gender differences in interests. The teacher failed to consciously design mixed-group tasks requiring cross-skill and cross-gender collaboration, thus failing to effectively break down these naturally formed subgroup barriers.

C. INDIVIDUAL CENTRALITY DIFFERENCES AND INTERACTIVE RESOURCE ALLOCATION

The analysis of individual centrality reveals an uneven distribution of interactive resources in the classroom (Table 3). Teachers possess absolute initiative and influence, specifically manifested in their out-degree centrality (initiating interaction) being far higher than their in-degree centrality (being interacted with by students), clearly indicating that teachers are the sole core driver of classroom interaction. Students' in-degree centrality (the interaction they receive)

varies significantly.

As shown in Table 3, the student with the highest in-point centrality (e.g., student A) reached 45%, meaning that nearly half of the class interactions were directly or indirectly directed towards him (mainly from passing and guidance from teachers and peers). The student with the lowest in-point centrality (e.g., student D) had only 3%, almost entirely excluded from mainstream interactions. Out-point centrality measures the initiative to initiate interactions, and those students ranked highest were also central students. Median centrality measures a node's ability to act as a "bridge" between other nodes. Students with high median centrality (e.g., students A and B) play a crucial mediating role in information dissemination, while marginal students have near-zero median centrality, meaning they receive neither attention nor connect with other classmates. This significant difference in centrality reflects the "Matthew effect" in classroom interaction opportunities: skilled and active students receive more attention, guidance, and opportunities to showcase their abilities, potentially further solidifying their advantage; while less skilled and introverted students struggle to progress and feel included due to a lack of interaction opportunities, falling into a vicious cycle. This unequal allocation of interaction resources not only hinders educational equity but also poses a potential threat to the athletic interest, self-confidence, and social development of marginal students.

V. CONCLUSION

This study successfully visualized and analyzed the interactive structure of physical education classes using social network analysis techniques, bridging the gap between physical pedagogy and the collaborative technical environments found in the industry to address the challenge of quantifying classroom social networks. By mapping these dynamics, the research provides a data-driven framework for optimizing the complex interpersonal synergies essential for mastering modern production processes. Empirical data revealed structural characteristics in classroom interaction, including prominent centralization, homogeneous subgroups, and uneven resource allocation. The study also analyzed the causes of these characteristics within the context of the teaching environment, proposing targeted improvement pathways for teaching. The proposed improvement pathways are closely integrated with engineering pedagogy. For example, to address the issue of homogeneous grouping, the concept of "blending" in production can be adopted to design "cross-skill, cross-gender" mixed-group tasks. This allows students

TABLE 3. Examples of Individuality Centrality Indicators

Student ID	Gender	In-degree and centrality	Point-wise centrality	Intermediate centrality	Relative Influence Ranking
Student A (basketball captain)	male	45%	15%	12.3	1
Student B (Active Female)	female	28%	10%	5.6	2
Student C (Ordinary male)	male	15%	8%	1.2	10
Student D (Marginalized Boy)	male	3%	2%	0.1	38
Student E (Marginalized Girl)	female	5%	1%	0.0	40

of different levels to complement each other's strengths and weaknesses in collaboratively completing a complex "weaving" task (such as tactical coordination), breaking down skill and gender barriers. To address the limited interaction opportunities for marginalized students, the "role rotation" mechanism from automated production lines can be introduced. A "role rotation" system can be designed for classroom exercises to ensure that every student can assume a core role in the interaction (such as a tactical organizer), thereby forcibly redistributing interaction resources and avoiding the "Matthew effect." However, as a case study, the generalizability of its conclusions needs further validation in classrooms across different grade levels, sports, and cultural backgrounds. Future research could incorporate multimodal data, such as speech and posture captured during machinery operation, to dynamically reveal the evolutionary mechanisms of interactive structures and promote the refined development of evidence-based physical education.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of Sichuan University of Media and Communications, and was performed in accordance with the principles of the Declaration of Helsinki. All eligible participants signed an informed consent form.

AUTHOR CONTRIBUTIONS

Conceptualization –Yong Wang, Li Zhu and Mingbang Li; methodology – Yong Wang, Li Zhu and Mingbang Li; investigation – Yong Wang, Li Zhu and Mingbang Li; writing-original draft preparation – Yong Wang, Li Zhu and Mingbang Li. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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