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Network Analysis of Teaching Self-Efficacy and Tacit Knowledge Sharing among Clinical Nursing Preceptors: A Multicenter Cross-Sectional Study

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Research Article

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Abstract

Background: Clinical nursing preceptors play a central role in translating classroom knowledge into clinical competence. Teaching self-efficacy and tacit knowledge sharing are important components of precepting capacity, yet their item-level associations remain unclear. This study examined the network structure of teaching self-efficacy and tacit knowledge sharing among clinical nursing preceptors and identified central and bridge items to inform future preceptor training.

Methods: A multicenter cross-sectional survey was conducted from February to June 2026 among 1221 clinical nursing preceptors from four hospitals in Guangyuan, Sichuan Province, China. Data were collected using a demographic questionnaire, the Clinical Teacher Tacit Knowledge Sharing Scale, and the Chinese version of the Clinical Nursing Teachers' Teaching Self-Efficacy Scale. A regularized partial-correlation network was estimated using a Gaussian graphical model with graphical least absolute shrinkage and selection operator regularization. Strength, closeness, betweenness, and bridge strength were calculated. Bootstrapping was used to assess edge accuracy and centrality stability. Network comparison tests were conducted by age, precepting experience, and frequency of preceptor training.

Results: The mean teaching self-efficacy score was 167.78 ± 38.44, and the mean tacit knowledge-sharing score was 36.96 ± 4.65. The network included 32 nodes and 234 non-zero edges. The strongest edge connected exchanging work-related experience with nurses and sharing information on key procedural techniques. High strength centrality was observed for items related to creating learning opportunities, multidisciplinary collaboration, and optimizing clinical teaching based on interns' assessment results. Bridge strength was highest for items related to expressing experience during learning activities, communication guidance, and sharing work-related know-how. The correlation stability coefficient for strength centrality was 0.60. Network structures differed by age group and frequency of preceptor training, but not by precepting experience.

Conclusions: Teaching self-efficacy and tacit knowledge sharing among clinical nursing preceptors formed an interconnected item-level network. Learning opportunity creation, feedback-informed teaching adjustment, multidisciplinary collaboration, and tacit knowledge externalization may represent candidate priorities for future preceptor training. Given the cross-sectional self-report design, these findings should be interpreted as exploratory associations rather than causal evidence.

Background

Nursing workforce development has shifted from expanding headcount to strengthening competency, practice readiness, and continuing professional development. The World Health Organization (WHO) identifies investment in nursing education, employment, and leadership as a policy lever for health-system resilience, with education quality, workforce competency, and leadership as priorities for 2021–2025 [1, 2]. The National Academies and the American Association of Colleges of Nursing (AACN) emphasize that nursing education should develop clinical judgment, collaborative practice, health equity,

knowledge integration, evidence-based practice, and quality improvement competencies [3, 4]. Clinical practice teaching links classroom knowledge with real-world care competence. Through procedural guidance and situated demonstration, clinical nursing preceptors help nursing students and novice nurses develop clinical judgment, communication skills, professional values, and safety awareness [5]. Precepting behaviors are associated with students' clinical competence, learning experience, and practice adaptation, and are influenced by teaching competence, feedback and assessment, organizational support, training, and experience [5–7]. Precepting competence includes teaching confidence, instructional strategies, experience transfer, situational judgment, and professional development. Continuing professional development helps nurses update knowledge and skills, but its implementation is shaped by organizational culture, supportive environments, professional motivation, and practice barriers [8]; clinical preceptor training can improve nurses' engagement in student education and precepting behaviors [9]. Evidence on clinical mentor roles, development of clinical teaching competence, and clinical education frameworks provides a basis for strengthening preceptor capacity [10–12].

Teaching self-efficacy is rooted in Bandura's social cognitive theory and refers to clinical nursing preceptors' judgment of their ability to complete teaching tasks, promote student learning, and achieve teaching goals [13]. This construct includes designing learning opportunities, integrating theory with practice, providing assessment and feedback, participating in academic activities, fulfilling precepting responsibilities, and pursuing professional development [14, 15]. Clinical teachers' self-efficacy affects teaching engagement, behavioral choices, and responses to complex situations, and is associated with core practice competence, teaching readiness, individual characteristics, and student evaluations [14, 16, 17]. Structured clinical teaching training and web-based teaching programs can improve teaching competence, self-efficacy, reflective teaching, and feedback skills [18, 19]. Tacit knowledge sharing refers to experiential resources in clinical precepting that are difficult to standardize but important for practice adaptation, including procedural know-how, communication skills, situational judgment, problem-solving approaches, and professional values [20]. Nursing knowledge-management studies show that both explicit and tacit knowledge sharing are related to clinical decision-making, organizational trust, competency development, and quality of care [21, 22]. Knowledge-sharing behavior is positively associated with ambidextrous leadership, perceived organizational support, and organizational commitment, suggesting that organizational support and management climate jointly shape knowledge sharing [23]. Existing scales classify clinical precepting tacit knowledge sharing into skill-based and cognitive dimensions. The Clinical Teacher Tacit Knowledge Sharing Scale (CTKS) and the Chinese version of the Clinical Nursing Teachers' Teaching Self-Efficacy Scale (CSE), which includes five dimensions—facilitating student learning, integrating theory and practice, participating in academic activities, fulfilling precepting responsibilities, and personal professional development—provide a measurement basis for item-level analysis [24, 25]. Knowledge-management systems can help nurses access, organize, and apply practice knowledge, supporting the organizational value of tacit knowledge sharing [26].

Most studies on clinical nursing precepting have used total-score correlations, regression, or latent class analysis to describe precepting competence, teaching behaviors, knowledge-sharing levels, and their influencing factors, but these methods cannot reveal conditional item-level associations or candidate key nodes [27]. Network analysis treats scale items as nodes and pairwise associations after controlling for other nodes as edges, allowing identification of central nodes, bridge nodes, and cross-construct connections [28, 29]. Network estimation requires assessment of edge-weight accuracy and centrality stability. Bridge centrality identifies nodes connecting different constructs or communities, and network comparison tests examine between-group differences in network structure and global strength [28, 30, 31]. Network analysis has been used in health research on cancer, cardiovascular disease, and diabetes, but its application to clinical nursing precepting competence and tacit knowledge sharing remains limited [32–34]. Nursing studies on burnout, team resilience, and performance have identified central nodes and bridge variables through network analysis, providing methodological support for this study [35, 36]. Therefore, this study constructed an item-level network of teaching self-efficacy and tacit knowledge sharing, identified central and bridge nodes, and compared network structures by age, precepting experience, and frequency of preceptor training, aiming to provide exploratory item-level evidence for preceptor training, tacit knowledge externalization, and clinical nursing education quality improvement.

Methods

- Study Design and Participants

This multicenter cross-sectional survey was conducted from February to June 2026 in four hospitals in Guangyuan, Sichuan Province, China. Convenience sampling was used to recruit clinical nursing preceptors who were responsible for clinical nursing teaching at each participating hospital. The study was organized with support from the lead institution and nursing management departments of the participating hospitals. Participation was voluntary. Hospital coordinators involved in survey administration did not evaluate individual responses or participate in data analysis, reducing potential influence from the management context. Reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline for cross-sectional studies [37].

The inclusion criteria were as follows: holding a registered nurse license; being engaged in clinical nursing and clinical precepting; providing informed consent and voluntary participation; and being able to understand and complete the questionnaire independently. The exclusion criteria were absence from actual clinical precepting during the survey period because of further training, leave, or external study, or inability to complete the questionnaire independently for other reasons. After checks for completeness, response time, logical consistency, and abnormal response patterns, 1221 valid participants were included. Because this study used multicenter convenience sampling within one region rather than random sampling, generalization to other regions, hospital levels, or nursing education management models should be cautious.

This study included 32 item-level nodes: 24 items from the Clinical Nursing Teachers' Teaching Self-Efficacy Scale (CSE) and 8 items from the Clinical Teacher Tacit Knowledge Sharing Scale (CTKS). Given the large number of parameters in item-level network models, a regularized partial-correlation network was used to reduce the risk of spurious edges and overfitting. Bootstrapping was applied to assess edge-weight accuracy and centrality stability.

- Measures

2.2.1 Demographic and Professional Characteristics Questionnaire
The demographic and professional characteristics questionnaire was developed by the researchers based on the study aim and relevant literature. It included sex, age, educational level, marital status, employment type, professional title, position, years of work experience, years of precepting experience, frequency of preceptor training, pre-employment training, regular qualification review, and full-time preceptor status. These variables were used to describe participants' demographic and work-related characteristics.

2.2.2 Clinical Teacher Tacit Knowledge Sharing Scale
Tacit knowledge sharing was assessed using the Clinical Teacher Tacit Knowledge Sharing Scale (CTKS) developed by Xu and Qian [24]. The CTKS evaluates the extent to which clinical nursing preceptors share experiential, contextual, and practice-based knowledge during teaching. Based on the Socialization, Externalization, Combination, and Internalization (SECI) knowledge-management model, the scale was developed through literature review, qualitative interviews, expert consultation, and pilot testing. It contains two dimensions and 8 items: skill-based tacit knowledge sharing with 5 items and cognitive tacit knowledge sharing with 3 items. Items are rated on a 5-point Likert scale, with total scores ranging from 8 to 40; higher scores indicate higher levels of tacit knowledge sharing. In this study, Cronbach's α values for skill-based tacit knowledge sharing, cognitive tacit knowledge sharing, and the total CTKS were 0.925, 0.977, and 0.965, respectively.

2.2.3 Clinical Nursing Teachers' Teaching Self-Efficacy Scale
Teaching self-efficacy was assessed using the Chinese version of the Clinical Nursing Teachers' Teaching Self-Efficacy Scale (CSE), translated and validated by Sun et al. [25]. The CSE evaluates clinical nursing preceptors' confidence and perceived ability to complete clinical teaching tasks. It includes five dimensions: facilitating student learning, integrating theory and practice, participating in academic activities, fulfilling precepting responsibilities, and focusing on personal professional development. The scale contains 24 items, with 7, 4, 5, 5, and 3 items in these dimensions, respectively. All items are positively scored on a 10-point Likert scale ranging from 0, "not confident at all," to 9, "extremely confident." Total scores range from 0 to 216, with higher scores indicating greater teaching self-efficacy. In this study, Cronbach's α values for the five dimensions ranged from 0.969 to 0.976, and Cronbach's α for the total CSE was 0.991.

Node codes, dimensions, and item meanings are shown in Table 1.

Table 1
Node Codes, Dimensions, and Item Meanings

Node	Dimension	Item meaning
CSE1	Facilitating student learning	Design new teaching strategies to improve clinical nursing teaching
CSE2	Facilitating student learning	Create learning opportunities to help interns adapt to the clinical environment
CSE3	Facilitating student learning	Select appropriate teaching strategies to support effective intern learning
CSE4	Facilitating student learning	Develop plans to support interns who experience difficulties during clinical practice
CSE5	Facilitating student learning	Select effective assessment strategies according to different clinical scenarios
CSE6	Facilitating student learning	Optimize clinical teaching processes based on interns' assessment results
CSE7	Facilitating student learning	Continuously adjust and innovate teaching strategies to meet interns' diverse learning needs
CSE8	Integrating theory and practice	Understand the intrinsic link between coursework and clinical practice
CSE9	Integrating theory and practice	Understand the relationship between curriculum design and clinical practice design
CSE10	Integrating theory and practice	Understand how practice content meets course learning objectives
CSE11	Integrating theory and practice	Develop core clinical teaching content aligned with practice objectives
CSE12	Participating in academic activities	Use best evidence and clinical knowledge to plan clinical teaching activities scientifically
CSE13	Participating in academic activities	Actively participate in academic activities as a team member
CSE14	Participating in academic activities	Independently design and conduct research in one's specialty
CSE15	Participating in academic activities	Apply current evidence and information to improve clinical nursing teaching skills
CSE16	Participating in academic activities	Promote the integration of clinical practice, teaching, and research through multidisciplinary collaboration
CSE17	Fulfilling precepting responsibilities	Recognize one's leadership role as a clinical nursing preceptor in clinical teaching

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items.

Node	Dimension	Item meaning
CSE18	Fulfilling precepting responsibilities	Serve as a mentor for interns, newly employed nurses, and junior preceptors in clinical practice
CSE19	Fulfilling precepting responsibilities	Balance clinical precepting, theoretical teaching, academic research, and clinical work
CSE20	Fulfilling precepting responsibilities	Foster a respectful, collaborative, professional, progressive, and caring atmosphere in clinical work
CSE21	Fulfilling precepting responsibilities	Promote reform and innovation in clinical nursing education
CSE22	Focusing on personal professional development	Participate in professional activities to achieve personal growth goals
CSE23	Focusing on personal professional development	Identify personal professional development needs and clarify areas for improvement
CSE24	Focusing on personal professional development	Improve clinical teaching skills through self-reflection, practice experience, and professional development
CTKS1	Skill-based tacit knowledge sharing	Willingly share acquired work-related know-how with other nurses
CTKS2	Skill-based tacit knowledge sharing	Privately guide nurses in communication skills when nurse–patient communication is poor
CTKS3	Skill-based tacit knowledge sharing	Express one's ideas for reference when participating in training, lectures, or other learning activities
CTKS4	Skill-based tacit knowledge sharing	Share problem-solving methods when nurses seek help
CTKS5	Skill-based tacit knowledge sharing	Share successful work experience with other nurses to help them
CTKS6	Cognitive tacit knowledge sharing	Exchange work-related experience with nurses when they seek advice
CTKS7	Cognitive tacit knowledge sharing	Actively convey values of professional dedication and patient-centered care to nurses
CTKS8	Cognitive tacit knowledge sharing	Share known information on key procedural techniques when nurses ask

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items.

- Data Collection and Quality Control

Data were collected using a questionnaire survey. Before data collection, the research team provided standardized training for survey coordinators from the four participating hospitals, covering inclusion and exclusion criteria, questionnaire distribution, informed consent procedures, anonymous completion,

and quality-control standards. All hospitals used the same questionnaire, instructions, and submission rules. A total of 1300 questionnaires were distributed, and 1221 valid questionnaires were returned, yielding an effective response rate of 93.9%. Eligible clinical nursing preceptors completed the questionnaire independently after providing informed consent. Researchers and hospital coordinators did not interfere with the response process to reduce interviewer bias and social desirability bias.

After collection, questionnaires were checked for completeness, response time, logical consistency, and abnormal response patterns to exclude clearly invalid or low-quality responses. After data entry, all data were organized using unified codes, and logical consistency among age, years of work experience, years of precepting experience, professional title, and position was reviewed. The statistical database contained no personally identifiable information, such as names, employee IDs, or phone numbers, to protect participants' privacy and improve data quality.

Ethics Approval

This study was conducted in accordance with the Declaration of Helsinki and medical research ethics principles. Ethics approval was obtained from the Ethics Committee of Guangyuan Central Hospital, the lead institution, with approval number 2026-022. The study was implemented after approval from the nursing management departments of all participating hospitals. Before the survey, participants were informed of the study purpose, content, completion method, data use, potential risks and benefits, privacy protection measures, and voluntary participation. All participants provided informed consent and could withdraw at any time before submitting the questionnaire without any effect on their work, training, assessment, or related rights. Questionnaires were completed anonymously, and the research database contained no personally identifiable information, including names, employee IDs, or phone numbers. All data were used only for data analysis and academic reporting, and results were presented in aggregate form without identifying individuals.

Statistical Analysis

R software (version 4.3.3) was used for data management, descriptive analysis, common method bias testing, reliability analysis, and network analysis. Network estimation, centrality analysis, bridge strength analysis, network stability testing, and network comparison tests were performed using the qgraph, bootnet, networktools, and NetworkComparisonTest packages, respectively. Categorical variables were described as frequencies and percentages, and continuous variables as means and standard deviations. Harman's single-factor test was used for preliminary assessment of common method bias, and Cronbach's α was used to assess the internal consistency of the CTKS and CSE [38]. Following the original scoring method of the CSE, item scores were transformed to a 0–9 scale before dimension and total scores were calculated.

Item-level network analysis was conducted in R. This analysis was exploratory and used to describe the conditional correlation structure between CSE and CTKS items, not to infer causality. The 24 CSE items

and 8 CTKS items were included as nodes. Edges represented conditional correlations between two items after controlling for all other nodes in the network. Because the CTKS uses a 5-point Likert scale and the CSE uses a 10-point Likert scale, and all items were ordinal, item distributions were examined before network estimation. A polychoric correlation matrix suitable for ordinal items was used as the network input. The network structure was estimated using a Gaussian graphical model (GGM) and regularized with the graphical least absolute shrinkage and selection operator (graphical LASSO) and extended Bayesian information criterion (EBIC), producing a relatively stable and interpretable partial-correlation network [28, 29]. The EBIC tuning parameter γ was set to 0.5. In the network graph, thicker edges indicated larger absolute edge weights; blue edges indicated positive correlations, and red edges indicated negative correlations.

Strength, closeness, and betweenness centrality were used to describe the relative position of each node. Strength centrality was defined as the sum of the absolute edge weights connecting a node to all other nodes and mainly reflected direct connectivity. Closeness centrality represented the average shortest path distance between a node and all other nodes. Betweenness centrality reflected the extent to which a node lay on the shortest paths between other nodes. Bridge strength was used to identify bridge nodes connecting teaching self-efficacy and tacit knowledge sharing [30]. For bridge strength calculation, CSE items and CTKS items were specified as two communities.

Bootstrapping was used to assess the accuracy and stability of network estimation [28]. Edge-weight accuracy was evaluated using 95% confidence intervals (CIs) from 1000 bootstrap samples. Centrality stability was assessed using the correlation stability coefficient from case-dropping bootstrap analysis. A correlation stability coefficient > 0.25 is generally considered acceptable, and > 0.50 indicates good stability. Because closeness and betweenness centrality are more sensitive to sampling variation in cross-sectional psychological and behavioral networks, interpretation of central nodes was based mainly on strength centrality.

Network comparison tests were used to assess network structure invariance and global strength invariance across subgroups [31]. Based on career stage, accumulated precepting experience, and exposure to preceptor training, participants were grouped by age (< 35 years vs ≥ 35 years), precepting experience (< 5 years vs ≥ 5 years), and frequency of preceptor training (less frequent vs frequent participation). The less frequent group included participants who had never or occasionally participated in training. Statistical significance was set at $\alpha = 0.05$. This study focused on item-level conditional associations between teaching self-efficacy and tacit knowledge sharing; therefore, survey center was not used as a grouping variable for network comparison. Potential differences in nursing education management systems, training resources, and organizational support across the four hospitals were considered as possible sources of heterogeneity when interpreting the results.

Results

- Participant Characteristics

A total of 1221 clinical nursing preceptors from four hospitals in Guangyuan, Sichuan Province, China, were included. Most participants were female (n = 1151, 94.3%). The largest age groups were 30–34 years (n = 420, 34.4%) and 35–39 years (n = 326, 26.7%). Most had a bachelor's degree (n = 1053, 86.2%) and were married (n = 1058, 86.7%).

Regarding professional characteristics, 791 participants (64.8%) held non-established positions, 687 (56.3%) had intermediate professional titles, and 890 (72.9%) had no administrative or teaching management role. Work experience was mainly 11–15 years (n = 398, 32.6%) or > 15 years (n = 392, 32.1%). Precepting experience was < 5 years in 425 participants (34.8%) and 5–10 years in another 425 participants (34.8%). Frequent participation in preceptor training was reported by 641 participants (52.5%). Most had received pre-employment training (96.7%) and regular qualification review (94.0%), and 1014 participants (83.0%) were not full-time preceptors. Participant characteristics are shown in Table 2.

Table 2
Participant Characteristics (n = 1221)

Variable	Category	n (%)
Sex	Male	70 (5.7)
	Female	1151 (94.3)
Age group	< 30 years	194 (15.9)
	30–34 years	420 (34.4)
	35–39 years	326 (26.7)
	40–45 years	140 (11.5)
	> 45 years	141 (11.5)
Educational level	Associate degree	143 (11.7)
	Bachelor's degree	1053 (86.2)
	Master's degree or above	25 (2.0)
Marital status	Married	1058 (86.7)
	Unmarried	122 (10.0)
	Divorced/widowed	39 (3.2)
	Other	2 (0.2)
Employment type	Established position	403 (33.0)
	Contract/personnel agency	27 (2.2)
	Non-established position	791 (64.8)
Professional title	Junior	362 (29.6)
	Intermediate	687 (56.3)
	Associate senior or above	172 (14.1)
Position	None	890 (72.9)
	Team leader	214 (17.5)
	Ward head nurse	88 (7.2)
	Department head nurse	29 (2.4)
Years of work experience	< 5 years	107 (8.8)

Note: Categorical variables are presented as n (%). Percentages may not total 100% because of rounding.

Variable	Category	n (%)
	5–10 years	324 (26.5)
	11–15 years	398 (32.6)
	> 15 years	392 (32.1)
Years of precepting experience	< 5 years	425 (34.8)
	5–10 years	425 (34.8)
	> 10 years	371 (30.4)
Frequency of preceptor training	Never	49 (4.0)
	Occasionally	531 (43.5)
	Frequently	641 (52.5)
Pre-employment training	No	40 (3.3)
	Yes	1181 (96.7)
Regular qualification review	No	73 (6.0)
	Yes	1148 (94.0)
Full-time preceptor status	No	1014 (83.0)
	Yes	207 (17.0)
Note: Categorical variables are presented as n (%). Percentages may not total 100% because of rounding.		

- Common Method Bias Testing and Scale Reliability

Harman's single-factor test was used to assess common method bias. An unrotated principal component analysis was performed on the 32 CSE and CTKS items. Two factors had eigenvalues > 1, and the first factor explained 69.674% of the variance, exceeding the commonly used 40% threshold. This suggested a potential risk of common method bias. Given the procedural controls used in this study, including anonymous completion, standardized instructions, independent responses, and academic-only data use, subsequent findings should be interpreted cautiously in light of possible common-source measurement bias and social desirability bias inherent in cross-sectional self-report surveys.

Cronbach's α analysis showed that the α for the total CTKS was 0.965. The α values for skill-based and cognitive tacit knowledge sharing were 0.925 and 0.977, respectively. The α for the total CSE was 0.991, and the α values for its five dimensions ranged from 0.969 to 0.976. All scale and dimension α values were > 0.900, indicating high internal consistency in this sample, but also suggesting possible item

homogeneity. This potential homogeneity should be considered when interpreting the findings. Reliability results are shown in Table 3.

Table 3
Reliability Analysis of the Scales and Dimensions

Scale/dimension	Number of items	Cronbach's α
Skill-based tacit knowledge sharing	5	0.925
Cognitive tacit knowledge sharing	3	0.977
Total CTKS	8	0.965
Facilitating student learning	7	0.971
Integrating theory and practice	4	0.974
Participating in academic activities	5	0.971
Fulfilling precepting responsibilities	5	0.969
Focusing on personal professional development	3	0.976
Total CSE	24	0.991

Note: CTKS = Clinical Teacher Tacit Knowledge Sharing Scale; CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale. Cronbach's α was used to assess internal consistency. Cronbach's α ≥ 0.700 is generally considered acceptable.

- Node Scores for Teaching Self-Efficacy and Tacit Knowledge Sharing

The total CTKS score was 36.96 ± 4.65, and the mean item score was 4.62 ± 0.58, indicating an overall high level with clustering toward higher scores for some items. Among the two CTKS dimensions, the mean item score for cognitive tacit knowledge sharing was slightly higher than that for skill-based tacit knowledge sharing (4.65 ± 0.61 vs 4.60 ± 0.58). At the item level, CTKS1, "willingly share acquired work-related know-how with other nurses," had the highest score (4.71 ± 0.57), whereas CTKS3, "express one's ideas for reference when participating in training, lectures, or other learning activities," had the lowest score (4.34 ± 0.87).

The total CSE score was 167.78 ± 38.44, and the mean item score was 6.99 ± 1.60. Dimension-level mean item scores ranged from 6.86 to 7.12. Facilitating student learning had the highest score (7.12 ± 1.56), whereas participating in academic activities had the lowest score (6.86 ± 1.72). At the item level, CSE2, "create learning opportunities to help interns adapt to the clinical environment," scored relatively high (7.34 ± 1.65), whereas CSE14, "independently design and conduct research in one's specialty," scored relatively low (6.65 ± 1.95). Node scores are shown in Table 4.

Table 4
Node Scores for CSE and CTKS (n = 1221)

Node	Dimension	Item meaning	Score range	Mean ± SD	Median (P25, P75)
CSE1	Facilitating student learning	Design new teaching strategies to improve clinical nursing teaching	0–9	6.70 ± 1.91	7 (5, 8)
CSE2	Facilitating student learning	Create learning opportunities to help interns adapt to the clinical environment	0–9	7.34 ± 1.65	7 (6, 9)
CSE3	Facilitating student learning	Select appropriate teaching strategies to support effective intern learning	0–9	7.21 ± 1.60	7 (6, 9)
CSE4	Facilitating student learning	Develop plans to support interns who experience difficulties during clinical practice	0–9	7.23 ± 1.65	7 (6, 9)
CSE5	Facilitating student learning	Select effective assessment strategies according to different clinical scenarios	0–9	7.13 ± 1.62	7 (6, 9)
CSE6	Facilitating student learning	Optimize clinical teaching processes based on interns' assessment results	0–9	7.09 ± 1.67	7 (6, 9)
CSE7	Facilitating student learning	Continuously adjust and innovate teaching strategies to meet interns' diverse learning needs	0–9	7.13 ± 1.70	7 (6, 9)
CSE8	Integrating theory and practice	Understand the intrinsic link between coursework and clinical practice	0–9	7.14 ± 1.71	7 (6, 9)
CSE9	Integrating theory and practice	Understand the relationship between curriculum design and clinical practice design	0–9	7.01 ± 1.71	7 (6, 8)
CSE10	Integrating theory and practice	Understand how practice content meets course learning objectives	0–9	7.08 ± 1.65	7 (6, 9)
CSE11	Integrating theory and practice	Develop core clinical teaching content aligned with practice objectives	0–9	7.05 ± 1.67	7 (6, 8)

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items, scored from 0 to 9; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items, scored from 1 to 5. SD = standard deviation; P25 and P75 indicate the 25th and 75th percentiles, respectively.

Node	Dimension	Item meaning	Score range	Mean ± SD	Median (P25, P75)
CSE12	Participating in academic activities	Use best evidence and clinical knowledge to plan clinical teaching activities scientifically	0–9	7.01 ± 1.71	7 (6, 8)
CSE13	Participating in academic activities	Actively participate in academic activities as a team member	0–9	7.01 ± 1.73	7 (6, 9)
CSE14	Participating in academic activities	Independently design and conduct research in one's specialty	0–9	6.65 ± 1.95	7 (5, 8)
CSE15	Participating in academic activities	Apply current evidence and information to improve clinical nursing teaching skills	0–9	6.85 ± 1.82	7 (6, 8)
CSE16	Participating in academic activities	Promote the integration of clinical practice, teaching, and research through multidisciplinary collaboration	0–9	6.76 ± 1.84	7 (6, 8)
CSE17	Fulfilling precepting responsibilities	Recognize one's leadership role as a clinical nursing preceptor in clinical teaching	0–9	7.00 ± 1.76	7 (6, 9)
CSE18	Fulfilling precepting responsibilities	Serve as a mentor for interns, newly employed nurses, and junior preceptors in clinical practice	0–9	6.93 ± 1.82	7 (6, 9)
CSE19	Fulfilling precepting responsibilities	Balance clinical precepting, theoretical teaching, academic research, and clinical work	0–9	6.83 ± 1.87	7 (6, 8)
CSE20	Fulfilling precepting responsibilities	Foster a respectful, collaborative, professional, progressive, and caring atmosphere in clinical work	0–9	7.15 ± 1.67	7 (6, 9)
CSE21	Fulfilling precepting responsibilities	Promote reform and innovation in clinical nursing education	0–9	6.72 ± 1.97	7 (6, 8)
CSE22	Focusing on personal professional development	Participate in professional activities to achieve personal growth goals	0–9	6.88 ± 1.81	7 (6, 8)

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items, scored from 0 to 9; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items, scored from 1 to 5. SD = standard deviation; P25 and P75 indicate the 25th and 75th percentiles, respectively.

Node	Dimension	Item meaning	Score range	Mean ± SD	Median (P25, P75)
CSE23	Focusing on personal professional development	Identify personal professional development needs and clarify areas for improvement	0–9	6.92 ± 1.80	7 (6, 8)
CSE24	Focusing on personal professional development	Improve clinical teaching skills through self-reflection, practice experience, and professional development	0–9	6.97 ± 1.76	7 (6, 8)
CTKS1	Skill-based tacit knowledge sharing	Willingly share acquired work-related know-how with other nurses	1–5	4.71 ± 0.57	5 (5, 5)
CTKS2	Skill-based tacit knowledge sharing	Privately guide nurses in communication skills when nurse–patient communication is poor	1–5	4.61 ± 0.63	5 (4, 5)
CTKS3	Skill-based tacit knowledge sharing	Express one's ideas for reference when participating in training, lectures, or other learning activities	1–5	4.34 ± 0.87	5 (4, 5)
CTKS4	Skill-based tacit knowledge sharing	Share problem-solving methods when nurses seek help	1–5	4.69 ± 0.58	5 (4, 5)
CTKS5	Skill-based tacit knowledge sharing	Share successful work experience with other nurses to help them	1–5	4.66 ± 0.62	5 (4, 5)
CTKS6	Cognitive tacit knowledge sharing	Exchange work-related experience with nurses when they seek advice	1–5	4.65 ± 0.62	5 (4, 5)
CTKS7	Cognitive tacit knowledge sharing	Actively convey values of professional dedication and patient-centered care to nurses	1–5	4.64 ± 0.64	5 (4, 5)
CTKS8	Cognitive tacit knowledge sharing	Share known information on key procedural techniques when nurses ask	1–5	4.65 ± 0.62	5 (4, 5)

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items, scored from 0 to 9; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items, scored from 1 to 5. SD = standard deviation; P25 and P75 indicate the 25th and 75th percentiles, respectively.

- Network Structure of CSE and CTKS

The estimated CSE–CTKS network included 32 nodes and 234 non-zero edges, indicating multiple conditional associations among items. The overall network structure is shown in Fig. 1. The strongest

edge connected CTKS6, “exchange work-related experience with nurses,” and CTKS8, “share information on key procedural techniques,” with an edge weight of 0.455. The next strongest edges were CSE6, “optimize clinical teaching processes based on interns’ assessment results,” and CSE7, “adjust and innovate teaching strategies to meet learning needs,” with an edge weight of 0.432; and CSE10, “understand how practice content meets course learning objectives,” and CSE11, “develop core clinical teaching content aligned with practice objectives,” with an edge weight of 0.410.

Network visualization showed within-construct clustering for both CSE and CTKS items, with stronger connections between semantically related items in the same construct. Within CTKS, cognitive and skill-based tacit knowledge sharing showed relatively strong connections, suggesting close associations among exchanging work experience, sharing procedural techniques, and guiding communication skills. However, this pattern may also reflect semantic overlap and clustering toward high scores.

Note

CSE = Clinical Nursing Teachers’ Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Edge thickness is proportional to the absolute edge weight. Blue edges indicate positive correlations, and red edges indicate negative correlations.

- Centrality and Bridge Strength

Centrality analysis showed that CSE2, “create learning opportunities to help interns adapt to the clinical environment”; CSE16, “promote the integration of clinical practice, teaching, and research through multidisciplinary collaboration”; and CSE6, “optimize clinical teaching processes based on interns’ assessment results,” had high strength centrality. These nodes had strong direct connections with other items and may represent candidate priorities for future clinical preceptor training.

For closeness centrality, CSE16, CSE17, “recognize one’s leadership role as a clinical nursing preceptor in clinical teaching,” and CSE15, “apply current evidence and information to improve clinical nursing teaching skills,” had higher scores. For betweenness centrality, CSE21, “promote reform and innovation in clinical nursing education”; CTKS1, “share acquired work-related know-how with other nurses”; and CTKS2, “privately guide nurses in communication skills,” had higher scores. Centrality results are shown in Fig. 2.

Note

CSE = Clinical Nursing Teachers’ Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Strength, closeness, and betweenness are standardized centrality indices.

Bridge strength analysis showed that CTKS3, “express one’s ideas for reference when participating in training, lectures, or other learning activities”; CTKS2, “privately guide nurses in communication skills”; and CTKS1, “share acquired work-related know-how with other nurses,” had higher scores. These

findings suggest that skill-related experience expression, communication guidance, and work-related know-how sharing may have strong cross-construct links with CSE items. Bridge strength results are shown in Fig. 3.

Note

CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Bridge strength indicates the extent to which a node connects the CSE and CTKS communities.

- Network Accuracy and Stability

To assess the accuracy and stability of network estimation, 1000 bootstrap samples were generated. The 95% confidence intervals (CIs) for edge weights indicated acceptable precision for major edges; however, some CIs were wide, suggesting estimation uncertainty for several network connections. These results should therefore be interpreted together with stability analyses. Edge-weight bootstrap results are shown in Fig. 4.

Note

CI = confidence interval; CIs = confidence intervals. Edge-weight accuracy was assessed using 1000 bootstrap samples. Wider CIs indicate greater uncertainty in edge-weight estimation.

Case-dropping bootstrap analysis showed that the correlation stability coefficient for strength centrality was 0.60, exceeding the recommended threshold of 0.50 and indicating good stability. Therefore, subsequent interpretation of central nodes was based mainly on strength centrality, whereas closeness and betweenness centrality were considered supplementary. Centrality stability results are shown in Fig. 5.

Note

Strength centrality stability was assessed using case-dropping bootstrap analysis. The correlation stability coefficient for strength centrality was 0.60.

- Network Comparison

Network comparison by age showed that 614 participants were aged < 35 years and 607 were aged ≥ 35 years. Network structure differed significantly between the two groups (M = 0.391, p = 0.010), whereas global strength did not (S = 0.032, p = 0.950). This suggests that item connection patterns may vary by age, although overall network connectivity was similar; however, the difference does not imply that age caused changes in network structure. Strength centrality by age group is shown in Fig. 6.

For precepting experience, 425 participants had < 5 years and 796 had ≥ 5 years of experience. No significant between-group differences were observed in network structure (M = 0.280, p = 0.178) or

global strength (S = 0.321, p = 0.683), suggesting similar connection patterns and overall connectivity across precepting-experience groups. Strength centrality by precepting experience is shown in Fig. 7.

For frequency of preceptor training, 580 participants were in the less frequent participation group and 641 in the frequent participation group. Network structure differed significantly between groups (M = 0.443, p = 0.010), whereas global strength did not (S = 1.259, p = 0.168). This indicates possible differences in item connection patterns by preceptor-training frequency, but the cross-sectional design precludes causal inference. Strength centrality by preceptor-training frequency is shown in Fig. 8. Network comparison results across subgroups are shown in Table 5.

Note

CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are the < 35 years and ≥ 35 years age groups.

Note

CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are participants with < 5 years and ≥ 5 years of precepting experience.

Note

CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are the less frequent and frequent participation groups.

Table 5
Network Comparison Results Across Subgroups

Comparison variable	Network structure (M)	p value	Global strength (S)	p value	Interpretation
Age (< 35 years vs ≥ 35 years)	0.391	0.010	0.032	0.950	Network structure differed significantly, whereas global strength did not, suggesting different connection patterns
Precepting experience (< 5 years vs ≥ 5 years)	0.280	0.178	0.321	0.683	No significant differences in network structure or global strength
Frequency of preceptor training (less frequent vs frequent participation)	0.443	0.010	1.259	0.168	Network structure differed significantly, whereas global strength did not; causal effects cannot be inferred

Note: M = test statistic for network structure invariance; S = test statistic for global strength invariance. p < 0.05 indicates statistical significance. p values are reported to three decimal places.

Discussion

4.1 Main Findings

Using data from 1221 clinical nursing preceptors, this study applied network analysis to examine item-level associations between teaching self-efficacy and tacit knowledge sharing. Overall, participants reported high levels of both constructs, with a total CSE score of 167.78 ± 38.44 and a total CTKS score of 36.96 ± 4.65. Reliability analysis showed high internal consistency for both scales. Harman's single-factor test suggested a potential risk of common method bias; therefore, findings should be interpreted cautiously given the cross-sectional self-report design. The CSE–CTKS network included 32 nodes and 234 non-zero edges. The strongest edge connected CTKS6, "exchange work-related experience with nurses," and CTKS8, "share information on key procedural techniques," followed by CSE6, "optimize clinical teaching processes based on interns' assessment results," and CSE7, "adjust and innovate teaching strategies to meet learning needs," and by CSE10, "understand how practice content meets course learning objectives," and CSE11, "develop core clinical teaching content aligned with practice objectives." Strength centrality was highest for CSE2, CSE16, and CSE6, whereas bridge strength was highest for CTKS3, CTKS2, and CTKS1. Network comparison showed structural differences by age and frequency of preceptor training, but no differences in network structure or global strength by precepting experience. These findings suggest that preceptor-related teaching competence may be reflected not only in overall CSE or CTKS levels, but also in item-level links involving learning opportunity creation, feedback use, interprofessional collaboration, experience expression, and communication guidance.

These results align with the recent shift in nursing education research from single-domain teaching competence assessment to integrated evaluation of competency, practice readiness, and continuing professional development. The World Health Organization and the National Academies emphasize that improving nursing education requires attention to workforce competence, clinical judgment, collaborative practice, and leadership development [1–3]. The American Association of Colleges of Nursing framework also includes knowledge integration, evidence-based practice, interprofessional collaboration, quality and safety, and professional development as core nursing education competencies [4]. At the item level, our findings help explain how these competency frameworks may manifest in clinical precepting: clinical teaching quality may depend not only on overall self-efficacy, but also on the connections among specific teaching behaviors, tacit knowledge externalization, and knowledge-sharing pathways.

4.2 Educational Implications of the CSE–CTKS Network Structure

In this study, CTKS6 and CTKS8 had the highest edge weight, indicating the strongest link between exchanging work-related experience and sharing key procedural techniques within the CTKS network. Tacit knowledge is contextual, experiential, and difficult to fully codify. When preceptors explain procedural techniques, they often also convey work experience, risk-recognition strategies, and situational judgment. The Socialization, Externalization, Combination, and Internalization (SECI) knowledge conversion model proposes that tacit knowledge is transformed at individual and organizational levels through socialization, externalization, combination, and internalization [20]. Thus, procedural guidance, experience exchange, and real-time feedback in clinical precepting can be viewed as processes that convert individual experience into learnable resources. Xu and Qian classified CTKS items 1–5 as skill-based tacit knowledge sharing and items 6–8 as cognitive tacit knowledge sharing, covering work-related know-how, communication skills, work experience, professional values, and procedural techniques [24]. The strong CTKS6–CTKS8 connection is consistent with this structure and suggests that CTKS among clinical nursing preceptors may involve not only willingness to share, but also situated demonstration and experiential explanation.

The strong CSE6–CSE7 and CSE10–CSE11 connections reflect internal teaching-design logic within CSE. CSE6 and CSE7 both relate to feedback-based teaching improvement, in which preceptors adjust teaching processes and strategies according to interns' assessment results. CSE10 and CSE11 both reflect alignment between course objectives and clinical teaching content. Clinical nursing teaching research shows that effective precepting involves creating learning environments, promoting student engagement, providing feedback and assessment, supporting theory–practice integration, and developing students' clinical judgment [5]. Hobenu et al. reported that undergraduate clinical nursing teaching should be improved at the student, clinical environment, and teacher levels, with teachers' strategies, feedback, and clinical learning environments influencing students' clinical competence [39]. Mathisen et al. found that practice education facilitators can strengthen clinical learning environments

by supporting students and clinical supervisors and promoting theory–practice integration, although these effects depend on organizational consensus, time allocation, and managerial support [40]. In this study, high-weight edges were mainly concentrated in two pathways: feedback-based teaching adjustment and alignment of curriculum objectives with clinical teaching content. This suggests that CSE item associations reflect not only teaching confidence, but also continuity among student assessment, teaching goals, and situated teaching strategies. Evidence on effective clinical teaching, clinical mentor selection, and clinical education frameworks also indicates that high-quality clinical teaching requires teacher role preparation, learning-goal alignment, supportive clinical learning environments, and student practice competence development [10–12].

In this study, the total CSE score and dimension-level item scores were high. Facilitating student learning had the highest score, whereas participating in academic activities had the lowest. This suggests that clinical nursing preceptors had strong confidence in creating learning opportunities, supporting clinical adaptation, and applying teaching strategies, but may need further development in academic activities, research design, use of current evidence, and integration of clinical practice, teaching, and research. Bourne et al. noted that clinical teacher self-efficacy is related not only to teaching behavior choices, but also to perceived control, role preparation, and professional identity development in complex clinical teaching contexts [14]. Shin et al. found that teaching efficacy among hospital nurse educators was associated with core practice competence, role stress, and individual characteristics [16]. Although participating in academic activities had the lowest score, CSE16 showed high strength centrality, suggesting that this item was closely connected with other items and may warrant attention in future preceptor training. This interpretation is based on network structure and requires validation through longitudinal or intervention studies.

4.3 CSE-Related Priorities Reflected by Central Nodes

CSE2, “create learning opportunities to help interns adapt to the clinical environment,” showed high strength centrality. The core task of clinical practice teaching is not simply transferring classroom knowledge to the bedside, but helping nursing students or novice nurses enter real care settings and develop practical competence through patient safety, teamwork, communication feedback, and clinical judgment. Zhang et al. reported in a qualitative meta-synthesis that students perceive effective clinical teaching behaviors as those that promote learning engagement, create supportive learning climates, provide clear demonstration and feedback, and help students build clinical confidence [5]. Creating clinical learning opportunities can connect multiple precepting behaviors, including procedural demonstration, communication guidance, feedback assessment, and professional role development. Thus, the high strength centrality of CSE2 is consistent with its role in linking multiple teaching behaviors. For nursing education management, CSE2 suggests that preceptor training should go beyond knowledge explanation and include identifying appropriate learning situations, designing progressive clinical tasks, and balancing patient safety with student practice opportunities.

CSE6, “optimize clinical teaching processes based on interns’ assessment results,” was another node with high strength centrality. Assessment and feedback are essential for clinical teaching quality improvement; they not only evaluate student performance, but also inform adjustments to teaching processes, strategies, and resource allocation. Clinical teaching studies show that preceptors’ feedback competence is related to students’ clinical competence and learning experience [5, 39]. In this network, CSE6 had a strong edge with CSE7, indicating a close link between using assessment results and adjusting teaching strategies. This finding suggests that assessment in clinical nursing precepting should not remain a summative score, but should be translated into evidence for teaching process improvement. Nursing education managers may consider CSE6 as a candidate focus for future preceptor training and quality-improvement programs, such as standardized precepting assessment forms, staged student feedback meetings, bedside teaching reviews, and closed-loop management of precepting problems.

CSE16, “promote the integration of clinical practice, teaching, and research through multidisciplinary collaboration,” ranked high in both strength and closeness centrality. Although this node belongs to the academic activities dimension, it was broadly connected with teaching design, professional development, and knowledge sharing in clinical precepting. The AACN framework includes interprofessional collaboration, evidence-based practice, and quality improvement as nursing education competencies; The Future of Nursing 2020–2030 also emphasizes nurses’ roles in collaborative practice and health equity within complex health systems [3, 4]. Clinical nursing preceptors have dual roles in clinical care and teaching. Their teaching quality depends not only on personal procedural experience, but also on multidisciplinary resource integration, clinical problem translation, and educational improvement capacity. The high strength centrality of CSE16 suggests that integration of clinical practice, teaching, and research may be broadly associated with clinical practice, teaching innovation, and professional development. Because this study used cross-sectional network analysis, CSE16 cannot be interpreted as a causal starting point; however, it may serve as a candidate indicator for future training and intervention studies.

4.4 Bridge Nodes Linking CTKS and CSE

Bridge strength analysis showed that CTKS3, CTKS2, and CTKS1 had high bridge strength between CSE and CTKS. Overall CTKS scores were high, and CTKS1, CTKS4, CTKS5, and CTKS6–CTKS8 showed high mean scores with clustering toward the upper range. This suggests strong tendencies toward sharing work-related know-how, experience, and procedural techniques, but also indicates that ceiling effects should be considered. CTKS3 had the lowest score but high bridge strength, suggesting that tacit knowledge sharing may occur not only through bedside guidance and procedural demonstration, but also through formal learning contexts such as training, lectures, and case reviews. Expressing clinical reasoning in formal learning activities may be an important link between the two constructs.

The high bridge strength of CTKS3 suggests that preceptors’ expression of clinical reasoning during training or lectures may be a key link between CSE and CTKS. Unlike bedside demonstration, this item

emphasizes how preceptors present reasoning, judgment processes, and experiential bases in formal learning contexts. Nursing knowledge-management studies show that knowledge sharing is related to organizational learning and innovation. Knowledge sharing among registered nurses is associated with decision-making processes, with organizational trust playing a mediating role; supervisors' knowledge-sharing behavior is positively related to nurses' innovative behavior and organizational learning; and a Capability, Opportunity, Motivation-Behavior (COM-B) model-based structural equation study showed that evidence-based nursing competence, nurse–physician collaboration, and innovation motivation were associated with knowledge-sharing behavior among surgical nurses [21, 41, 42]. Although these studies did not focus on clinical nursing preceptors, they collectively indicate links among knowledge sharing, organizational learning, collaboration, and innovation. The bridge strength of CTKS3 suggests that expressing ideas during training and lectures may provide opportunities to organize and share individual experience. Organizational knowledge-management systems can also support nurses in acquiring, organizing, and applying practice knowledge [26]. Given the clustering toward high scores for CTKS items, this interpretation still requires validation through longitudinal or intervention studies.

The high bridge strength of CTKS2 and CTKS1 also has clinical teaching implications. Privately guiding nurses when nurse–patient communication is poor reflects preceptors' immediate feedback on situational communication, patient experience, and professional roles. Sharing work-related know-how reflects the transfer of experiential skills from individual practice to others' practice. Scale-development research indicates that tacit knowledge in clinical precepting includes nursing procedural skills, know-how, thinking patterns, values, and experience [24]. A review of nursing knowledge-management systems showed that nurse leaders contribute to knowledge facilitation, creation of an organizational learning climate, and practice improvement [22]. Therefore, CTKS2 and CTKS1 reflect not only willingness to share, but also the process by which preceptors transform tacit experience into observable, learnable, and transferable teaching resources. These findings suggest that communication simulations, procedural know-how extraction, case reviews, and experience-sharing meetings could be incorporated into preceptor training to promote tacit knowledge externalization and organizational sharing.

4.5 Interpretation of Network Differences Related to Age and Training Frequency

Network comparison showed a significant difference in network structure between the < 35-year and ≥ 35-year groups, but no significant difference in global strength. This suggests that item connection patterns may differ by age, whereas overall network connectivity was similar. Age may reflect differences in career stage, accumulated clinical experience, role maturity, and opportunities for organizational participation; however, these factors were not longitudinally tracked or causally tested in this study. Research on clinical teacher self-efficacy shows that individual characteristics, core practice competence, and role stress can affect teaching efficacy. Bourne et al. also noted that clinical teacher self-efficacy is related to role preparation, experience, and teaching context [14, 16]. Therefore, age-related differences in network structure may reflect different links among learning opportunity creation, feedback use, professional development, and tacit knowledge expression. These findings do not indicate

that age causes network changes, but they may inform stage-specific training. Preceptors in younger or early-career stages may benefit from structured precepting procedures, communication and feedback templates, and standardized procedural demonstration, whereas more experienced preceptors may contribute to experience extraction, case repository development, and teaching improvement projects.

Network structure also differed significantly by frequency of preceptor training, whereas global strength did not. This suggests that frequent and less frequent training participants differed mainly in item connection patterns rather than in overall connectivity between CSE and CTKS. Previous studies indicate that training may improve precepting behaviors and self-efficacy, but this study cannot directly verify intervention effects. Wu et al. showed that a blended clinical teaching program improved teaching competence and self-efficacy among registered nurse preceptors. Hong and Yoon found that trained nurses showed better clinical teaching behaviors than untrained nurses, suggesting that training effects are not equivalent to accumulated precepting experience. Wong et al. reported that preceptors with different clinical teaching and training experiences had different training needs [6, 7, 18]. Mashayekh et al. further showed in a quasi-experimental study that preceptorship training significantly improved clinical nurses' overall participation in nursing student education and all related dimensions [9]. Our network comparison results are consistent with these findings, suggesting different item connection patterns by training frequency. However, these differences may also be influenced by age, work experience, role experience, and organizational support, and therefore should not be interpreted as a direct effect of training frequency.

No significant differences in network structure or global strength were observed by precepting experience. This suggests that simply accumulating years of precepting may not correspond to changes in the CSE–CTKS network structure. Clinical experience is an important basis for precepting competence, but whether experience is transformed into teaching competence may depend on reflective practice, feedback mechanisms, training quality, organizational support, and role identity. Rodrigues et al. found that web-based clinical teaching programs helped preceptors develop teaching self-awareness, feedback competence, and understanding of the clinical teaching role. Varghese et al. reported that preceptors supporting newly employed nurses faced time pressure, unclear responsibility boundaries, insufficient support, and learning needs [19, 43]. These findings suggest that precepting experience cannot replace structured teaching training and organizational support. Thus, using precepting years alone to stratify preceptor competence may be insufficient.

4.6 Implications for Nursing Education Management and Preceptor Training

Central node results suggest that clinical preceptor training may prioritize learning opportunity creation, feedback use, and integration of clinical practice, teaching, and research. For CSE2, training may include student competence assessment, graded clinical tasks, identification of bedside learning opportunities, and safety supervision. For CSE6, training may strengthen formative assessment, feedback conversations, interpretation of assessment results, and teaching process improvement. For CSE16,

training may include evidence-based teaching, interprofessional case discussion, teaching quality improvement, and translation of clinical problems into research. Compared with traditional training focused mainly on procedural demonstration, these priorities better align with WHO and AACN recommendations on nursing education quality, workforce competence, and interprofessional collaboration [1, 4].

Bridge node results suggest that clinical preceptor training and nursing management should strengthen tacit knowledge externalization. CTKS1, CTKS2, and CTKS3 correspond to sharing work-related know-how, guiding communication skills, and expressing ideas in learning activities, respectively. Hospitals may establish mechanisms such as standardized case reviews, documentation of exemplary precepting segments, discussions of difficult communication scenarios, precepting experience workshops, and departmental tacit knowledge repositories. Ominyi et al. noted that nurse managers can promote evidence-based knowledge use through leadership support, learning networks, and knowledge translation strategies, and that structured peer learning and informal mentoring can serve as knowledge-sharing mechanisms [44]. Knowledge-management studies also show that knowledge-sharing behavior is related to organizational learning, innovative behavior, and team collaboration [21, 22, 41, 42]. Incorporating tacit knowledge sharing into preceptor development may reduce reliance on individual memory and informal transmission, and support organizational retention and reuse of clinical teaching resources.

Network comparison results may inform stratified training. For younger preceptors or those with insufficient preceptor training, structured precepting pathways, communication scripts, student feedback templates, and simulated precepting scenarios may be prioritized. Older preceptors or those with frequent training may be encouraged to undertake teaching supervision, experience extraction, cross-departmental teaching improvement, and nursing education research. For preceptors with long precepting experience but limited training participation, managers should focus on tacit knowledge externalization and reflective practice rather than assigning precepting roles based only on years of experience. Beyond qualification access, clinical precepting systems should emphasize competence development, process feedback, knowledge retention, and continuous improvement. A study on clinical nurses' competency profiles found that educational level, willingness to participate in training, and perceived training importance were associated with higher competency profiles, and proposed profile-based stratified training strategies, which is consistent with the stratified training approach based on central and bridge nodes in this study [45]. These recommendations are based on the present network structure and prior training evidence, and their effects require testing in intervention studies.

4.7 Methodological Interpretation and Limitations

This study used a regularized partial-correlation network to estimate conditional associations between CSE and CTKS items, and used bootstrapping to assess network accuracy and centrality stability. Epskamp et al. emphasized that network analysis should report edge-weight accuracy and centrality stability to avoid overinterpreting unstable network structures [28]. In this study, the correlation stability coefficient for strength centrality was 0.60, exceeding the recommended threshold of 0.50 and indicating

good stability. This supports relatively robust structural interpretation of nodes such as CSE2, CSE16, and CSE6. However, closeness and betweenness centrality are generally more sensitive to sampling variation. Bringmann et al. cautioned that centrality indices in psychological networks should be interpreted carefully because their statistical meanings and practical implications are not identical [46]. Therefore, this study mainly discussed strength centrality and bridge strength, whereas closeness and betweenness centrality were used only as supplementary information and were not directly interpreted as intervention priorities. Previous network studies have also reported centrality, bridge variables, and network stability to improve transparency and reproducibility in item-level network interpretation [35, 36].

This study has limitations. First, multicenter convenience sampling was conducted within one region. Although 1221 participants from four hospitals in Guangyuan, Sichuan Province, were included, all centers were located in the same city; therefore, generalization to other provinces, hospital levels, or nursing education management models should be cautious. Second, all variables were measured using self-report questionnaires at one time point. Harman's single-factor test showed a high variance contribution from the first factor, indicating that common method bias, social desirability bias, and common-source measurement bias may affect interpretation. In addition, CTKS items showed marked clustering toward high scores, which may reduce variance and influence some edge-weight estimates. Finally, the cross-sectional design means that network edges represent conditional correlations after controlling for other nodes, and causal direction cannot be inferred. Rodebaugh et al. noted that central nodes in cross-sectional networks are not necessarily intervention targets; Castro et al. also emphasized that central and bridge symptoms require further longitudinal and experimental evidence before being treated as intervention targets [47, 48]. Thus, CSE2, CSE16, CSE6, CTKS3, CTKS2, and CTKS1 should be regarded as potential training priorities rather than causal factors leading to improved precepting competence.

Although this study used a multicenter design, between-center differences were not further analyzed, and survey center was not used as a grouping variable for network comparison. Hospitals may differ in nursing education management systems, training resources, organizational support, and precepting assessment mechanisms, which may affect item-level connections between CSE and CTKS. Because this study used item-level network analysis, semantic similarity among items and high internal consistency may have strengthened within-construct edge weights; therefore, strong edges should not be interpreted solely as evidence of distinct practical mechanisms. Future studies could combine item redundancy testing, dimension-level networks, longitudinal networks, and mixed-methods interviews to further clarify the practice mechanisms behind item connections. Studies across different regions and hospital levels, as well as pre–post training follow-up, longitudinal network analysis, or randomized controlled interventions, are needed to test whether training strategies targeting candidate central and bridge nodes can improve clinical precepting quality and tacit knowledge-sharing behavior.

Conclusions

This item-level network analysis preliminarily revealed the association structure between CSE and CTKS among clinical nursing preceptors. The results showed close item-level network links involving learning opportunity creation, feedback use, multidisciplinary collaboration, experience expression, communication guidance, and work-related know-how sharing. Items related to creating learning opportunities, optimizing clinical teaching processes based on interns' assessment results, and promoting the integration of clinical practice, teaching, and research through multidisciplinary collaboration showed high strength centrality, suggesting that these may be candidate connection points in the clinical precepting competence system. Expressing ideas during training or lectures, guiding communication skills, and sharing work-related know-how showed high bridge strength, indicating that tacit knowledge externalization may help explain cross-construct links between CSE and CTKS. Differences in network structure by age and frequency of preceptor training further suggest that item connection patterns may vary by career stage and training exposure. Nursing education managers may consider optimizing training around learning-situation design, formative assessment and feedback, interprofessional collaboration, and transformation of tacit experience, thereby supporting a shift in clinical precepting from individual experience transmission to competence development, knowledge sharing, and organizational knowledge retention.

Abbreviations

AACN
American Association of Colleges of Nursing
CI
Confidence interval
CIs
Confidence intervals
CSE
Clinical Nursing Teachers' Teaching Self-Efficacy Scale
CTKS
Clinical Teacher Tacit Knowledge Sharing Scale
EBIC
Extended Bayesian information criterion
GGM
Gaussian graphical model
LASSO
Least absolute shrinkage and selection operator
P25
25th percentile
P75
75th percentile
SD

Standard deviation
SECI
Socialization, Externalization, Combination, and Internalization
STROBE
Strengthening the Reporting of Observational Studies in Epidemiology
WHO
World Health Organization

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki. This study was approved by the Ethics Committee of Guangyuan Central Hospital, China (approval no. 2026-022). All participants were informed of the study purpose, procedures, questionnaire completion requirements, data use, privacy protection measures, and voluntary nature of participation before the survey. Informed consent was obtained from all participants. Participation was voluntary, and participants could withdraw before questionnaire submission without any influence on their work, training, or assessment. The questionnaires were completed anonymously, and all results are presented in aggregate form.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

JL and ZL contributed equally to this work. JL and ZL conceived and designed the study, coordinated data collection, performed the preliminary data analysis, and drafted the initial manuscript. CX participated in participant recruitment, questionnaire distribution, data collection, and data verification. MJ contributed to data management, statistical analysis, interpretation of the network analysis results, and manuscript revision. ZW supervised the study, contributed to the study design and methodology,

critically revised the manuscript for important intellectual content, and provided overall academic guidance. All authors read and approved the final manuscript.

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Data Availability

The datasets generated and/or analysed during the current study are not publicly available because they contain participant-level survey data and are subject to participant privacy, ethical restrictions, and institutional confidentiality. The de-identified data are available from the corresponding author on reasonable request and with permission from Guangyuan Central Hospital.

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Figures

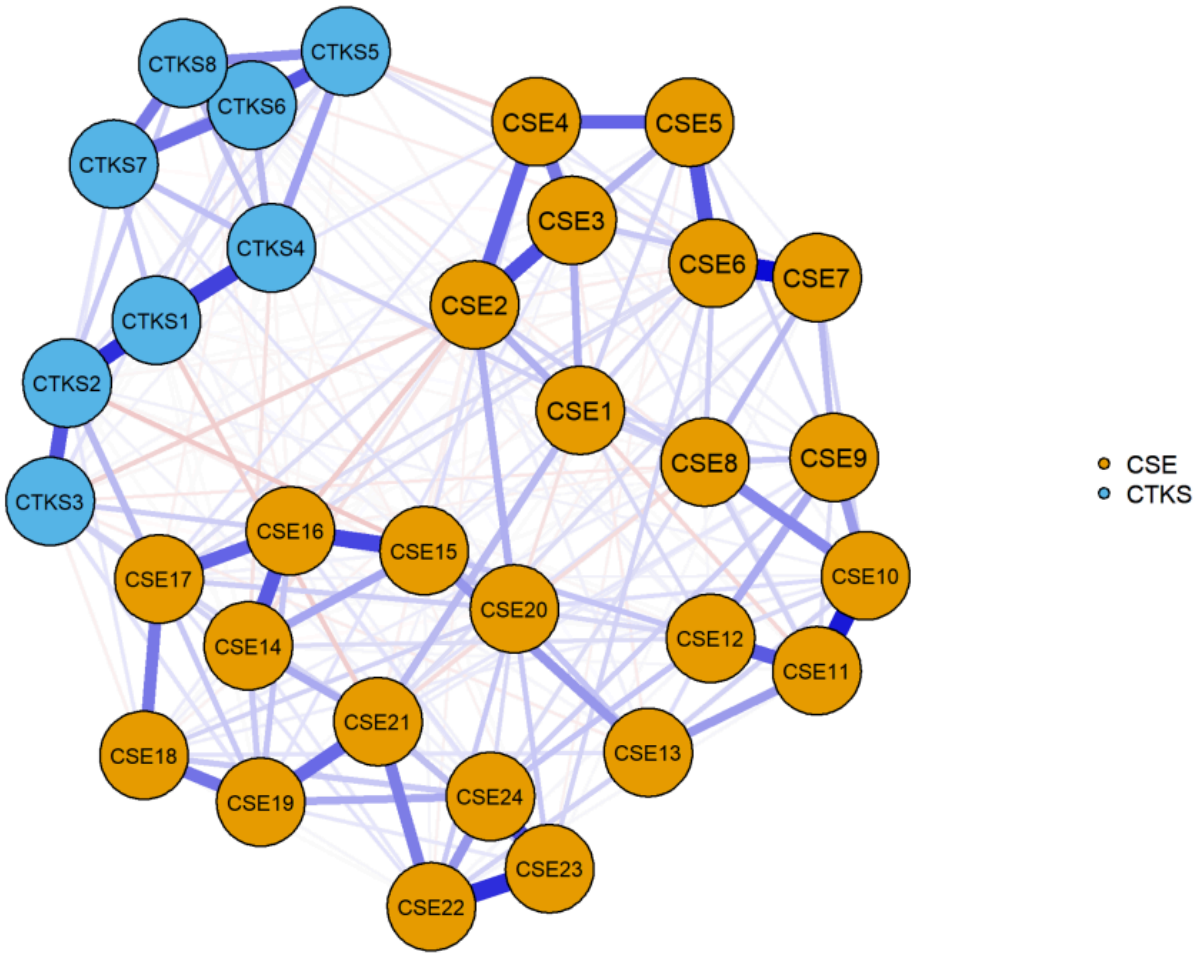


Figure 1

Network Structure of CSE and CTKS

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Edge thickness is proportional to the absolute edge weight. Blue edges indicate positive correlations, and red edges indicate negative correlations.

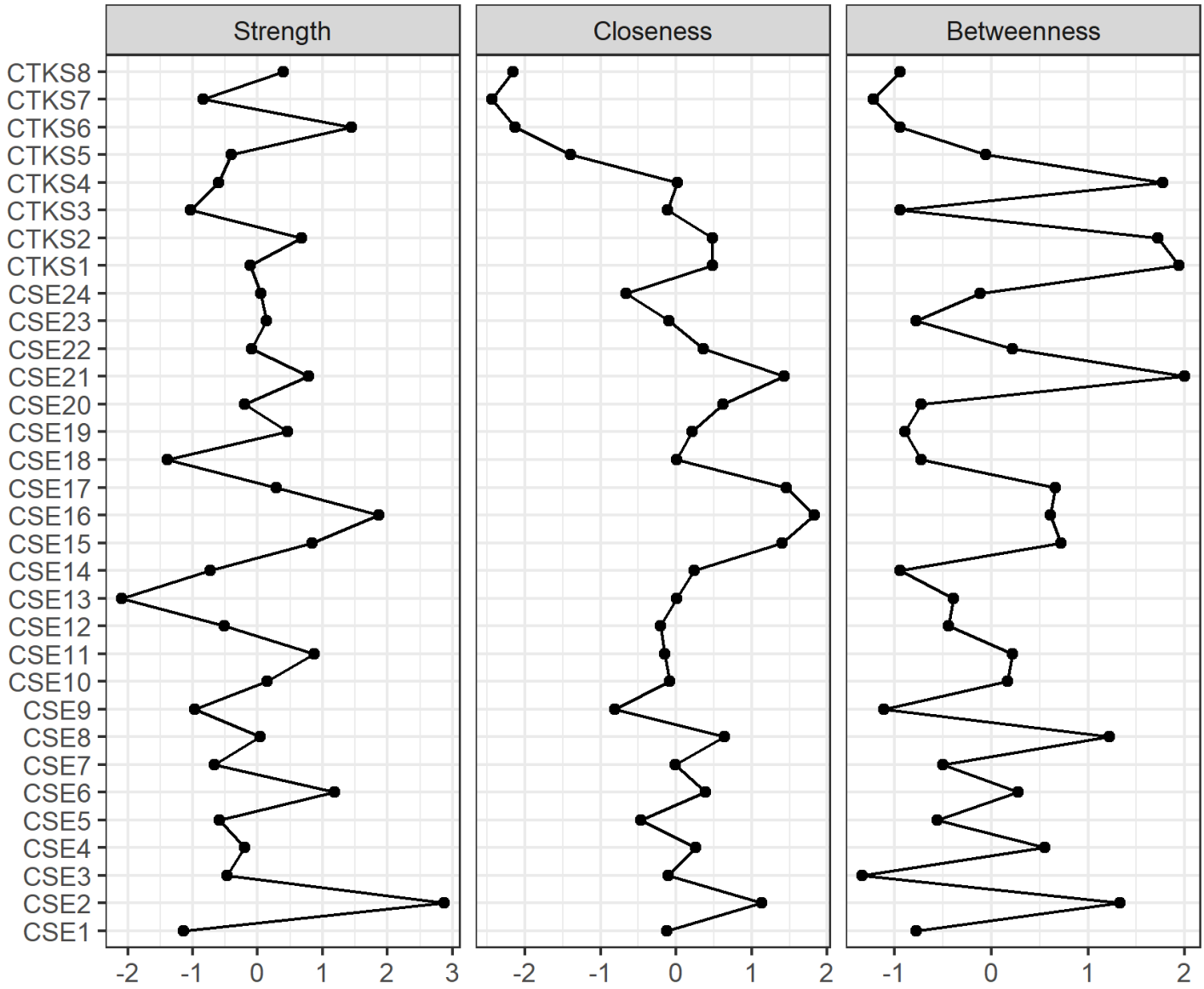


Figure 2

Centrality Indices

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Strength, closeness, and betweenness are standardized centrality indices.

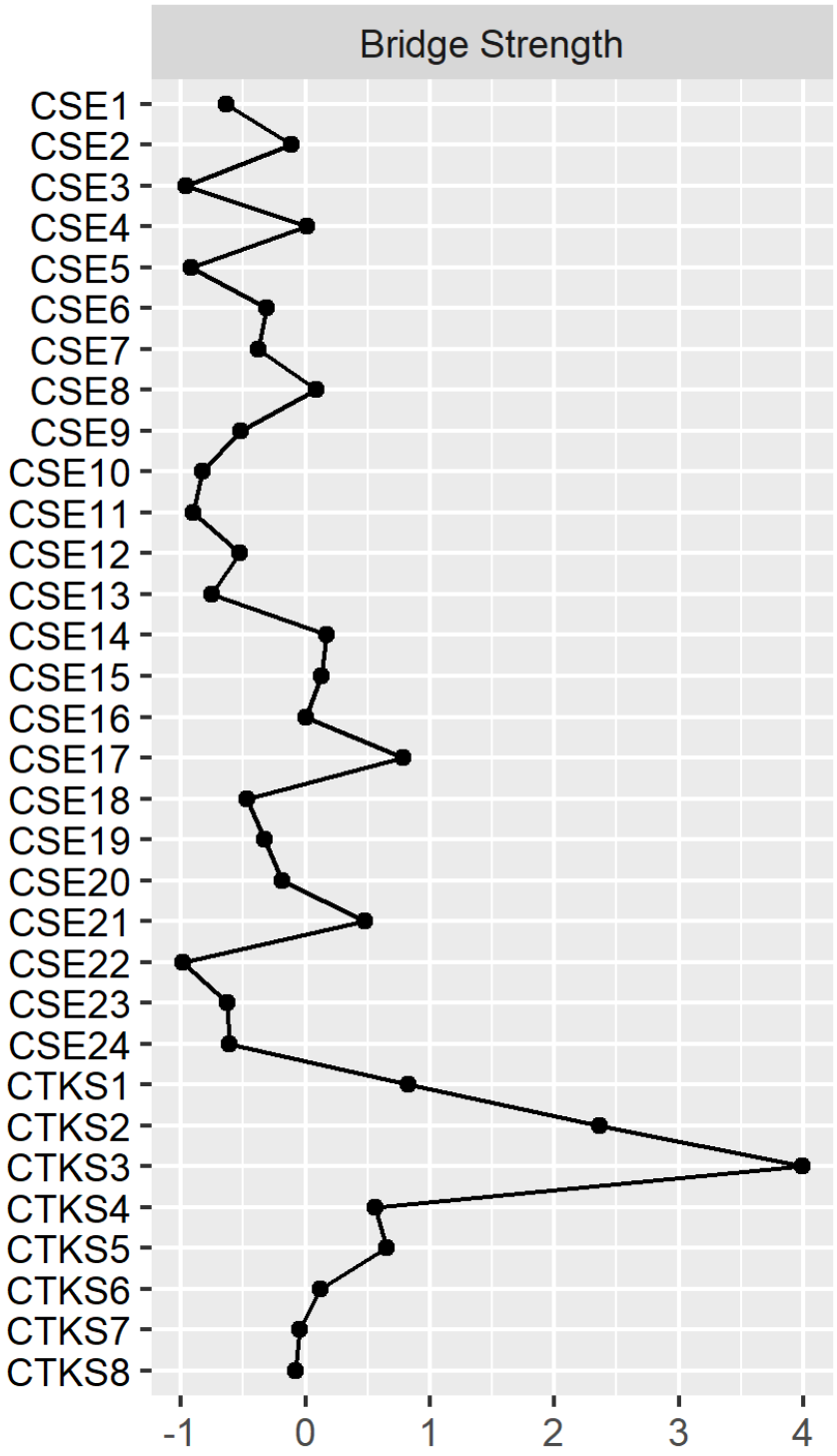


Figure 3

Bridge Strength Indices

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. Bridge strength indicates the extent to which a node connects the CSE and CTKS communities.

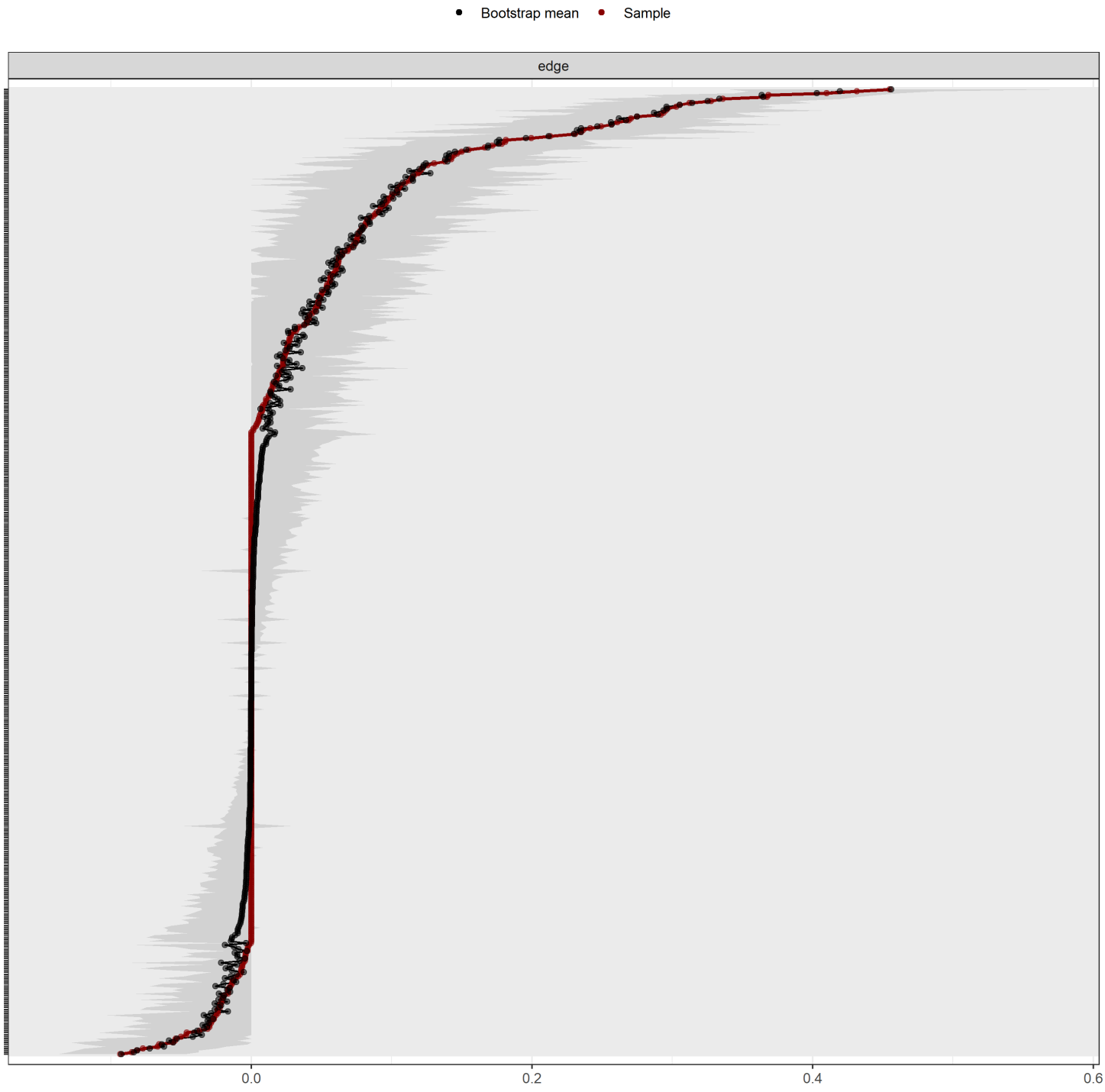


Figure 4

Bootstrap Results for Edge Weights

Note: CI = confidence interval; CIs = confidence intervals. Edge-weight accuracy was assessed using 1000 bootstrap samples. Wider CIs indicate greater uncertainty in edge-weight estimation.

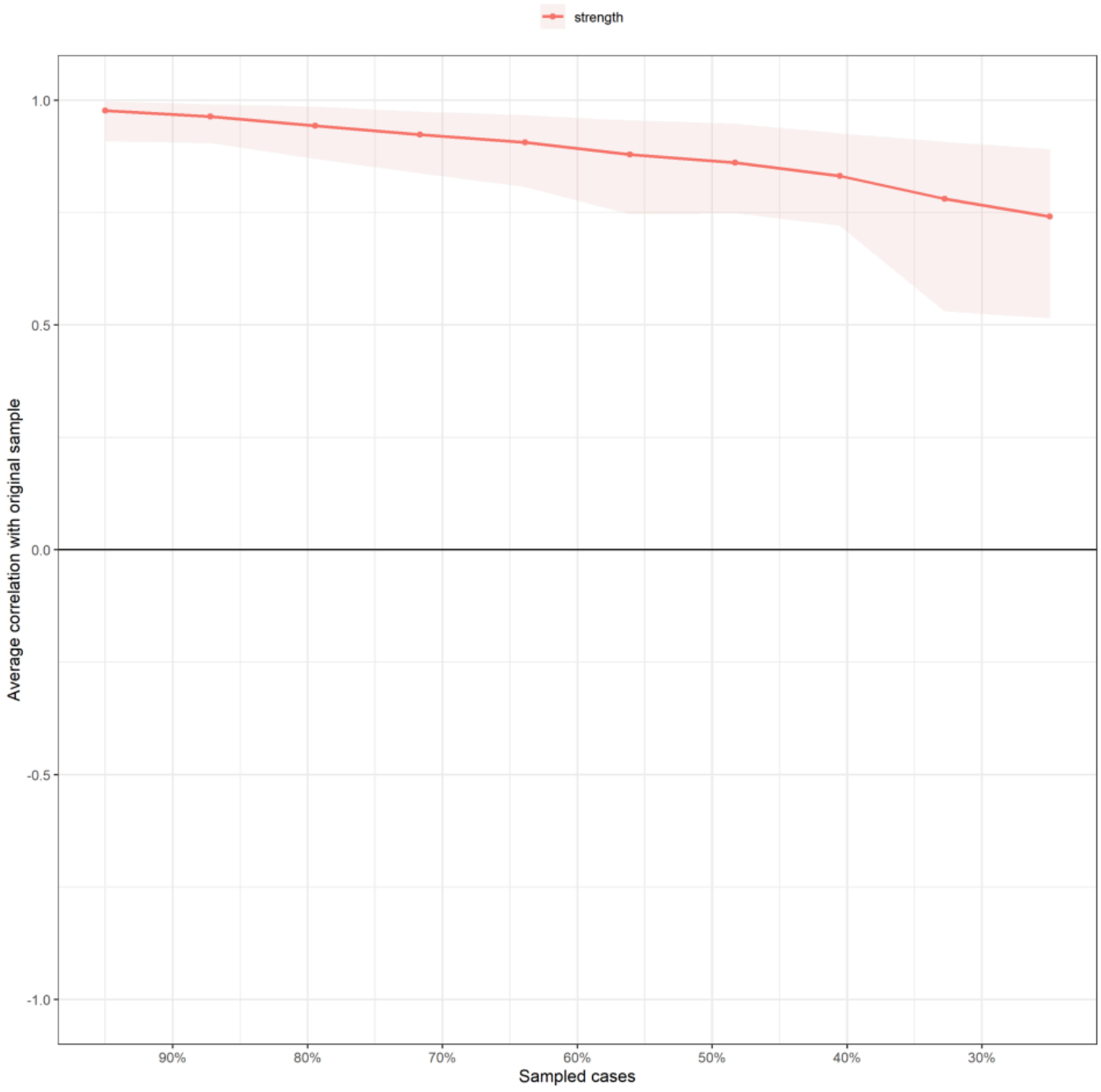


Figure 5

Stability of Strength Centrality

Note: Strength centrality stability was assessed using case-dropping bootstrap analysis. The correlation stability coefficient for strength centrality was 0.60.

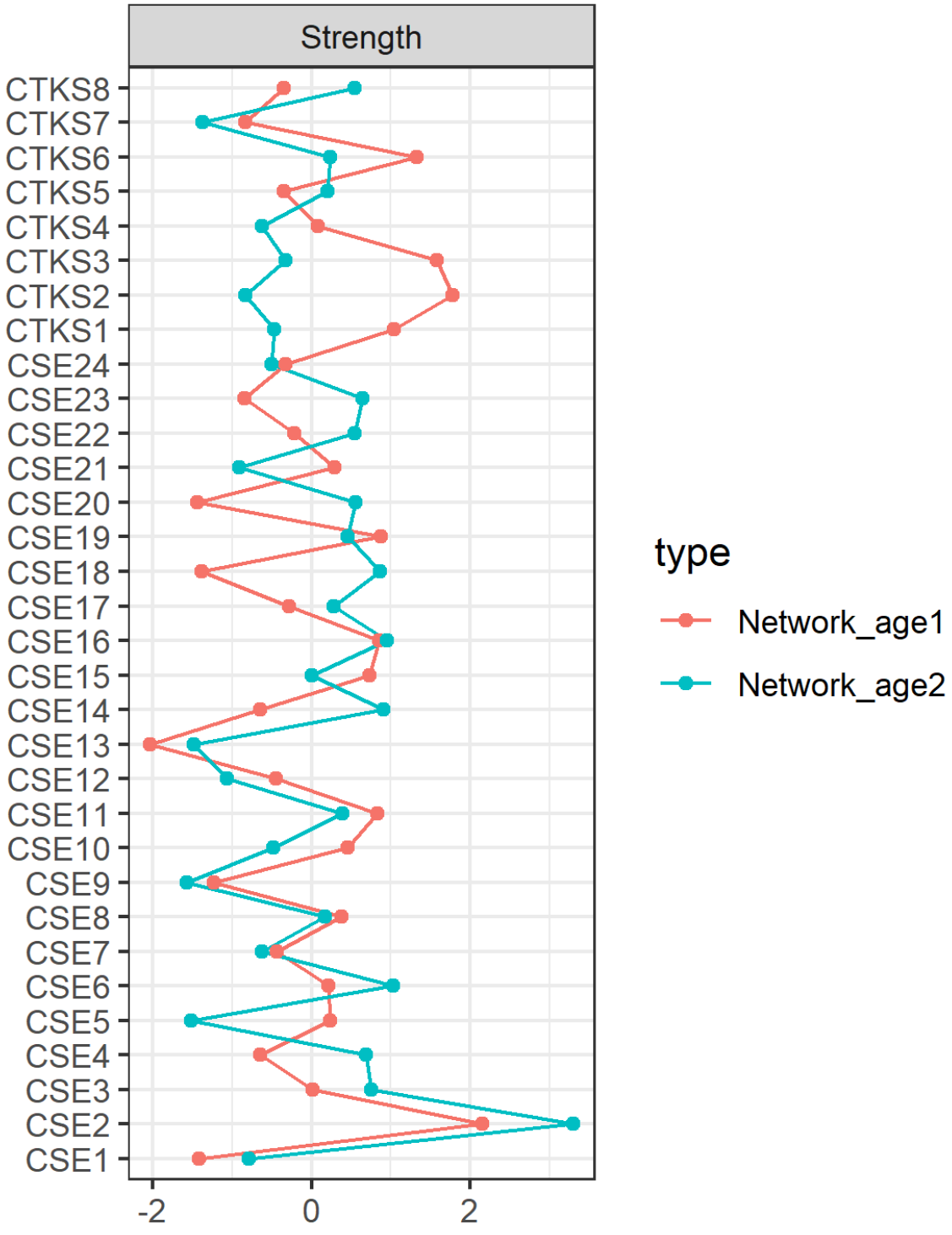


Figure 6

Strength Centrality by Age Group

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are the <35 years and ≥35 years age groups.

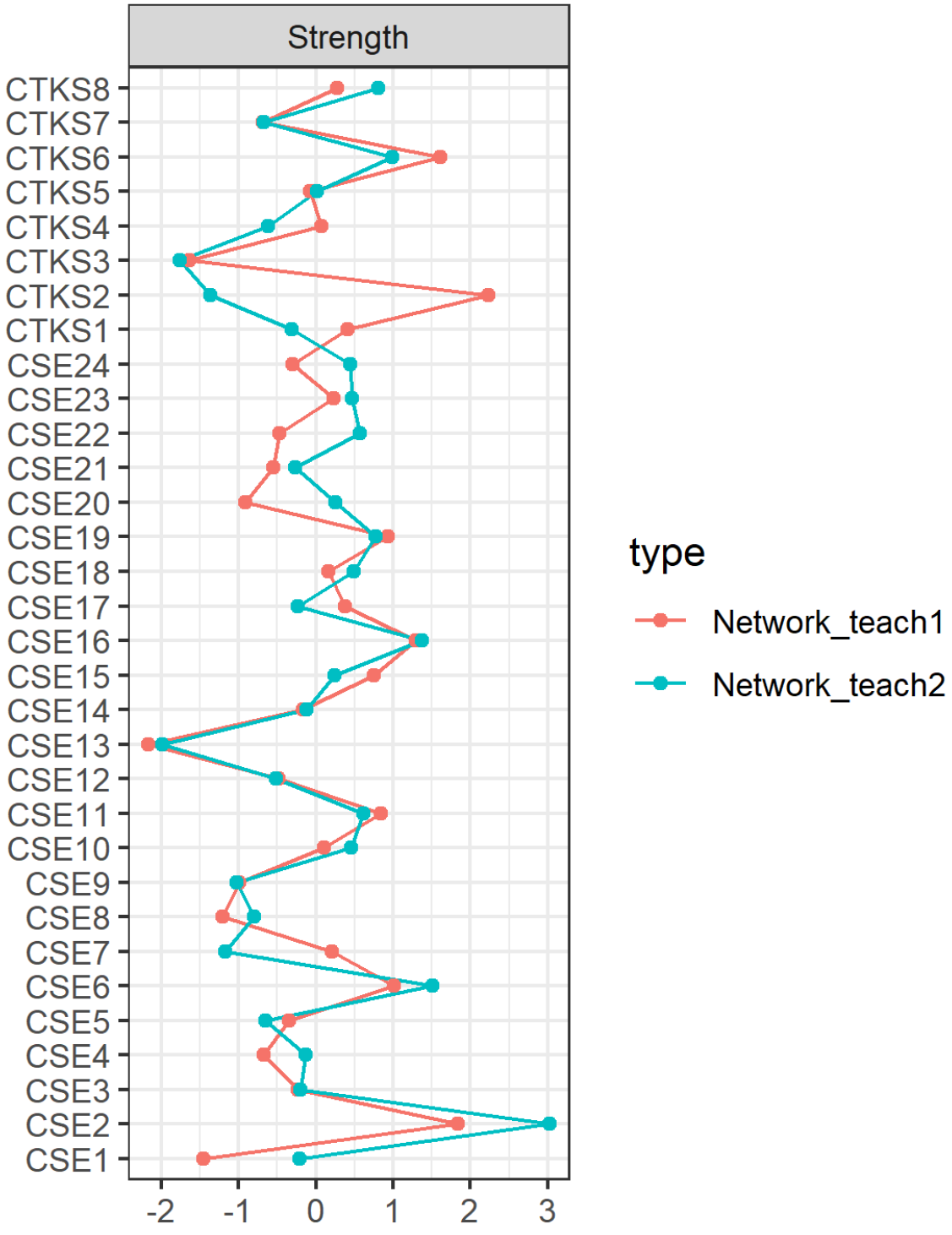


Figure 7

Strength Centrality by Precepting Experience

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are participants with <5 years and ≥5 years of precepting experience.

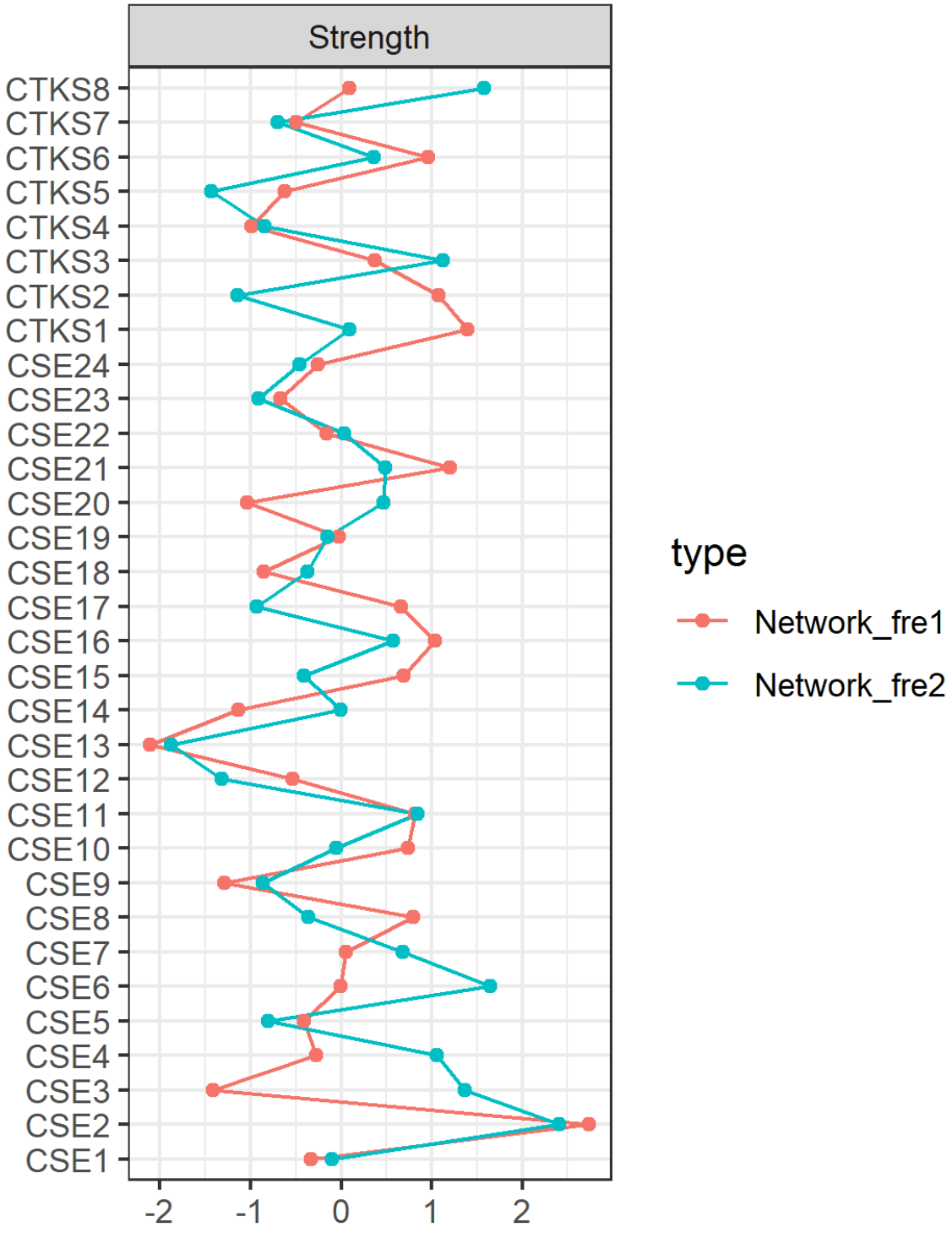


Figure 8

Strength Centrality by Frequency of Preceptor Training

Note: CSE = Clinical Nursing Teachers' Teaching Self-Efficacy Scale items; CTKS = Clinical Teacher Tacit Knowledge Sharing Scale items. The two groups are the less frequent and frequent participation groups.