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Construction and implementation of exploratory teaching model based on social network analysis

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Abstract: In order to solve the problems existing in traditional methods, such as the achievement rate of teaching objectives, learning participation rate and low academic performance, this paper puts forward a research method for the construction and implementation of exploratory teaching model based on social network analysis. Through questionnaire, online interactive platform monitoring and direct observation, the interaction data of students are collected, and the collected data are cleaned, and the social network analysis is carried out by using the cleaned data to determine the key nodes and groups among students. The inquiry teaching mode is constructed from the determination of learning objectives, the allocation of learning resources, the organisation of learning activities and the evaluation of learning effects. The maximum achievement rate of the proposed method of implementation is 93.1%, the maximum participation rate is 97.2%, and the maximum student academic performance is 90.2%.

Keywords: social network analysis; exploratory; teaching model; determination of learning objectives; allocation of learning resources; organisation of learning activities; evaluation of learning effects.

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1 Introduction

In today's rapidly developing education stage, the innovation of teaching mode is like a bright star, leading the trend of educational reform. Among many innovative teaching modes, inquiry teaching mode is like a fresh wind. With its unique teaching concept and vivid teaching methods, it has quickly emerged in the education field (Jesus et al., 2020). The inquiry-based teaching mode mainly takes students as the core, guides them to explore questions independently and actively seek answers, with the goal of improving students' autonomous learning ability. Compared with the traditional teaching mode based on teachers' lectures, inquiry teaching mode pays more attention to students' subjectivity and practicality, allowing students to feel the charm of knowledge in personal experience, exercise their abilities and expand their thinking in the process of inquiry (Coleman et al., 2023). This teaching mode not only helps to cultivate students' independent thinking and innovative ability, but also effectively improves students' practical ability, communication ability and teamwork ability, laying a solid foundation for future social development and personal growth (Gomez-Carrasco et al., 2022). Therefore, it is of great practical significance and far-reaching development prospect to conduct in-depth research on the construction and implementation methods of inquiry teaching mode. This is not only the only way to improve the quality of education and teaching, but also the key measure to promote educational innovation and cultivate talents in the new era.

Regarding the above research topic, Cai and Hu (2023) proposes a method for constructing and applying an inquiry based teaching model based on MOOCs. Deeply explore the essence of inquiry based teaching mode, which is a problem oriented and student-centred teaching strategy. A detailed analysis was conducted on the MOOC platform, and it was found that its advantages are significant, including a large student base, massive teaching resources, and flexible learning time. A research-based teaching model combining MOOC resources was proposed, including designing open questions, providing diversified learning resources, implementing online discussions and collaborative learning, and using data analysis tools to evaluate learning effectiveness. The analysis of the application effect of this mode shows that the participation rate of inquiry based learning is relatively low, and the actual application effect is not good. Chen et al. (2020) proposes a method for constructing and applying an exploratory teaching model based on the integration and application of knowledge among college students. In depth exploration of the core significance of research-based inquiry teaching,

a comprehensive analysis was conducted on the age group, knowledge structure, and specific roles played by students in society. The advantages of targeted exploration and free exploration were integrated, and a research-based inquiry teaching strategy for college students was proposed. The application effect of this method was verified from multiple aspects such as educational goals, educational concepts, and teaching principles. However, after analysis, it can be concluded that the achievement rate of exploratory teaching objectives under this method is relatively low and has not met the research expectations. Wang (2022) proposed the construction and application methods of an exploratory teaching model based on high school information technology issues. The basic principles of inquiry based teaching mode were elaborated, including problem driven, student led, process oriented, and authenticity. The construction process of inquiry based teaching mode was discussed in detail. At the application level, relevant application effectiveness evaluation results are obtained by selecting appropriate exploration topics, organising group collaborative learning, utilising technical tools to support the exploration process, and adopting multiple evaluation methods. However, through in-depth analysis, it can be concluded that the degree of improvement in students' academic performance under the application of this method is not significant, and the gap between it and the expected goals is not significant.

A new research method for the construction and implementation of exploratory teaching model based on social network analysis is proposed to solve the problems of low teaching goal achievement rate, learning participation rate, and learning performance in the above methods. This method has the characteristics of high teaching goal achievement rate, high learning participation rate, and high learning performance. The technical route of this method is as follows:

- 1 Collect student interaction data through survey questionnaires, online interactive platform monitoring, direct observation, etc., and clean and process the collected data.
- 2 Using cleaned data for social network analysis to identify key nodes and groups among students, such as subject leaders and active learners, and constructing an inquiry based teaching model from the determination of learning goals, allocation of learning resources, organisation of learning activities, and evaluation of learning outcomes.
- 3 The effectiveness of this method was verified by examining three indicators: the achievement rate of teaching objectives, the participation rate of learning, and the academic performance.

2 Construction of inquiry teaching model based on social network analysis

2.1 Student interactive data collection and cleaning processing

Before starting data collection, it is necessary to clarify the goals and scope of the collection, as well as the types of interaction data to be collected among students, such as email, instant messaging, social media communication, and participation in collaborative projects. At the same time, it is also necessary to determine the time frame for collecting data in order to comprehensively reflect the social network relationships among students.

Select appropriate data collection methods based on the collection objectives, including survey questionnaires, online interactive platform monitoring, direct observation, etc. A survey questionnaire can be designed with specific questions for students to self-report their social network relationships, mainly obtained through actual surveys; online interactive platform monitoring can record students' communication data in real-time, mainly through data crawling technology; direct observation allows for observing students' interactive behaviour in specific scenarios, mainly through actual surveys. Ensure that the data collection process is clear, consistent, and easy to follow, including clear guidance instructions, standardised question formats, and data input templates. Collect data from multiple sources and methods, and conduct cross validation to improve the accuracy and reliability of the data. The types of student interaction data are as follows:

- 1 Login and access data: record the time, frequency, and duration of students' login to the learning platform, as well as the course materials, resources, and tools they access.
- 2 Participation data: including students' participation in classroom discussions, group activities, online forums, and collaborative projects.
- 3 Homework and assessment data: students' homework submission status, completion time, quality rating, and scores from online tests and exams.
- 4 Interactive mode data: students' interactive patterns during the learning process, such as the frequency of questioning, communication methods with teachers and peers, etc.
- 5 Feedback and self-assessment data: students' evaluations of their learning progress, feedback on course content, and self-assessment results.
- 6 Technical usage data: the technical tools and equipment used by students during the learning process, as well as their proficiency and preferences towards these tools.
- 7 Emotional and motivational data: information collected through survey questionnaires, logs, or sensors on students' emotional states, learning motivation, and stress levels.
- 8 Social network data: students' social relationships, peer interactions, and network structures within the learning community.
- 9 Behavioural trajectory data: students' behavioural trajectories on the learning platform, such as clickstream data, page browsing order, and navigation paths.
- 10 Personalised settings data: students' personalised settings for the learning environment, such as font size, colour themes, learning reminders, etc.

Cleaning and sorting out the collected student interaction data, deleting irrelevant data and incomplete data to ensure the accuracy and reliability of the data (Long et al., 2022). Assume that there is a discrete random variable X in the collected student interaction dataset, and $A = \{a_1, a_2, \dots, a_q\}$ is its value. The entropy of the corresponding prediction probability of $p_i = P[X = a_i]$, X is defined as follows:

$$H(X) = E \log \frac{1}{p_i} = \sum_{i=1}^n p_i \log \frac{1}{p_i} = -p_i \log p_i \quad (1)$$

The pre-processing steps of student interaction data are as follows:

- Step 1 Assuming that the student interaction dataset A has n pieces of student interaction data and m attributes, the decision matrix about attribute values can be constructed as follows:

$$A = \begin{pmatrix} x_{11} & x_{21} & \cdots & x_{n1} \\ x_{12} & x_{22} & \cdots & x_{n2} \\ \cdots & \cdots & \cdots & \cdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{pmatrix} \quad (2)$$

In the above formula, x_{nm} represents the value of the m^{th} attribute in the student interaction data in article n .

- Step 2 Standardise the student interaction data. The data is compressed to the interval $[0, 1]$, and the sum of all data in each column is 1, that is, $\sum_{i=1}^n x_{ij} = 1$.

Students' interaction data with different dimensions and descriptions can be compared in a unified way (Al-Janabi and Janicki, 2022), and the calculation formula for calculating the proportion of j attributes of student interaction data in article i is as follows:

$$M_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}} \quad (3)$$

- Step 3 The calculation formula of the entropy value of the j^{th} attribute is as follows:

$$H_j = -\ln n \sum_{i=1}^n M_{ij} \ln M_{ij} \quad (4)$$

- Step 4 Calculate the entropy redundancy, and the specific calculation formula is as follows:

$$D_j = 1 - H_j \quad (5)$$

- Step 5 The formula for calculating the weight of the j -th attribute is as follows:

$$Y_j = \frac{D_j}{\sum_{j=1}^m D_j} \quad (6)$$

d people from different fields were organised to rate the attributes respectively, and the results are shown in Table 1.

The calculation formula of attribute grade is as follows:

$$V_j = \frac{\sum_{i=1}^d V_{ij}}{d}, 1 \leq j \leq m \quad (7)$$

In the above formula, V_{ij} indicates the rating of the i^{th} user on the j^{th} attribute (Rahul and Banyal, 2021; Li et al., 2024).

The formula for calculating the weight of the x^{th} attribute is as follows:

$$G_x = \frac{V_x}{\sum_{j=1}^m V_j}, 1 \leq j \leq m \quad (8)$$

Table 1 Attribute evaluation grade

	Attribute 1	Attribute 2	...	Attribute m
1	V_{11}	V_{12}	...	V_{1m}
2	V_{21}	V_{22}	...	V_{2m}
...	...	...	...	...
d	V_{d1}	V_{d2}	...	V_{dm}

In the above formula, V_x represents the x^{th} attribute.

Step 6 According to the above calculation of attribute weights, combine the weights determined by the two methods through comprehensive weighting to obtain the final comprehensive attribute weight, and the calculation formula of this value is as follows:

$$W = \frac{1}{2} \left(\frac{Y_j}{\sum_{j=1}^m Y_j} + \frac{G_j}{\sum_{j=1}^m G_j} \right), 1 \leq j \leq m \quad (9)$$

The calculated weights of m attribute values are sorted, and the comprehensive weight of attribute j is assigned 1~ m from small to large, and each attribute level determined after the comprehensive weight calculation is obtained.

Suppose that cluster combination CG of student interaction data cluster C is represented by a quadruple (n, A, N, W) . In this quad, n is the total amount of student interaction data in C , A is the set of all attribute values of student interaction data in C , $A_i = \{a_1, a_2, \dots, a_u\}$, and N is the total number of attributes corresponding to each attribute value in A in class C . The four elements in the cluster combination CG are denoted as $CG.n$, $CG.A$, $CG.N$ and $CG.W$ respectively. Suppose $X_i (i = 1, 2, \dots, n)$ represents any record in class C , and its corresponding attribute value can be empty, then the members of cluster combination $CG(n, A, N, W)$ of class C can be calculated by the following formula:

$$\left\{ \begin{array}{l} CG.n = n \\ CG.A = X_1 \cup X_2 \cup \dots \cup X_n \\ CG.N = \sum_{k=1}^n |a_j \cap X_k|, a_j \in CS.A, j = 1, 2, \dots, u \end{array} \right. \quad (10)$$

In the above formula, $CG.W$ represents the weight of each attribute in $CG.A$.

When a new student interaction record X is added, the new record should be compared with the corresponding record in the existing CG -cluster representation. When the similarity of a record exceeds the preset critical value, the record will be classified

into the corresponding category, and the cluster representative corresponding to this category will also be updated synchronously. The similarity between the new record and the current cluster representative is quantified and calculated by the following formula:

$$Sim(X, CG) = \frac{\sum_n \frac{1}{n} (X_i \cap CG.A) * W_k}{\sum_{n+1} \frac{1}{n+1} (X_i \cap CG.A) * W_k} \quad (11)$$

In the above formula, X_i represents each element in the new record, and W_k represents the weights corresponding to the attributes of each element in the cluster representation CG . The Euclidean distance between two n -dimensional vectors $x_1(x_{11}, x_{12}, \dots, x_{1n})$ and $x_2(x_{21}, x_{22}, \dots, x_{2n})$ is calculated as follows:

$$d(x_1, x_2) = \sqrt{\sum_{k=1}^n (x_{1k} - x_{2k})^2} \quad (12)$$

After the cluster grouping is completed, similar duplicate records are detected in each cluster grouping, corresponding records are deleted or merged, and the cleaned dataset is output.

2.2 Social network analysis based on student interaction data

Social network analysis (Garg and Wu, 2022; Xu et al., 2022) can comprehensively consider the complex relationships between students, between students and teachers, and between students and resources, thus providing a deep understanding of the whole learning network structure. This comprehensiveness makes it possible to grasp students' learning dynamics and interaction patterns more accurately. The inquiry teaching mode pays attention to students' active exploration and practice, and the social network analysis based on students' interaction data can reveal the cooperation mode and interaction mode between students, which provides strong support for inquiry learning. By analysing students' interactive data, teachers can find students' cooperative behaviour, information sharing and problem solving methods in the process of inquiry, so as to guide students to conduct inquiry learning better and ensure the quality of inquiry teaching mode construction (Wu et al., 2021). The novelty of the social network analysis method based on student interaction data is as follows:

- 1 Data driven insights: traditional educational research often relies on teacher observation and student self-report, while social network analysis methods based on student interaction data can provide more objective and quantitative insights. By analysing students' behaviour trajectories, discussion engagement, collaboration patterns, and other data on learning platforms, traditional methods can reveal learning patterns and social structures that are difficult to detect.
- 2 Real-time and dynamic: with the development of educational technology, student interaction data can be collected and analysed in real-time, which enables social network analysis to reflect the dynamic changes in student networks. Researchers can track the development trend of student networks over time and adjust teaching strategies in a timely manner to meet the changing needs of students.

- 3 Personalised learning support: social network analysis can help identify students' positions and roles in the learning network, thereby providing support for personalised learning. For example, by identifying key students, teachers can provide more targeted guidance and support, promoting students' learning outcomes.

This article combines clustering coefficient, proximity centrality, betweenness centrality, and eigenvector centrality for social network analysis, and uses label propagation algorithm to detect communities, in order to determine key nodes and groups among students, such as subject leaders and active learners, which can ensure the accuracy of the analysis results and provide technical support for subsequent research.

In social network analysis, clustering coefficient is a crucial index, which is used to describe the aggregation degree between nodes in the network, that is, the connection degree between adjacent nodes. In social networks, nodes with high clustering coefficient usually represent a close social circle or community. These nodes are closely connected and have high information dissemination efficiency, which has an important impact on the information dissemination and the spread of social influence in social networks (Acharoui et al., 2021). The calculation formula of clustering coefficient is as follows:

$$C_k = \frac{2 * e}{z * (z - 1)} \quad (13)$$

In the above formula, k represents a social network node, e represents the number of relationships passing through k neighbouring nodes, and z represents a first-order neighbouring node of k .

The calculation formula of closeness to centrality (Kasper, 2021) is as follows:

$$C_u = \frac{1}{\sum_{v=1}^{n-1} d(u, v)} \quad (14)$$

In the above formula, u represents the node to be calculated that is close to centrality, n represents all the nodes in the graph, and $d(u, v)$ represents the shortest distance between node u and node v .

Intermediary centrality is used to measure the extent to which a node can become a 'middleman', that is, to what extent it controls others. Its calculation formula is as follows:

$$C_{B(V)} = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (15)$$

In the above formula, σ_{st} represents the number of shortest paths from node s to node t , and $\sigma_{st}(v)$ represents the number of passing node v in the shortest path from node s to node t .

The centrality of feature vectors is mainly based on the distribution of nodes' neighbours in the network, and the centrality of nodes is evaluated by a specific algorithm. The calculation formula of feature vector centrality is as follows:

$$EC(i) = x_i = c \sum_{j=1}^n a_{ij} x_j \quad (16)$$

In the above formula, x_i represents the feature vector centrality measure of node v_i , c represents the proportionality constant, and a_{ij} represents the elements in the adjacency matrix.

Combining the tag propagation algorithm to detect the community, the specific implementation steps are as follows:

- 1 Initialisation: assign a unique label to each node (if available), or randomly assign a label.
- 2 Label updating mechanism: in each iteration cycle, each node will re-evaluate its label and update it to the one with the highest frequency among neighbouring nodes.
- 3 Iteration: the above-mentioned label updating process will continue until all node labels remain stable and terminate.
- 4 Community identification: nodes with the same label are identified as belonging to the same community, and key nodes and groups among students, such as subject leaders and learning activists, can be identified by combining this value, so as to lay a solid foundation for the follow-up inquiry teaching mode construction.

2.3 Construction of inquiry teaching model based on social network analysis

Based on the results of social network analysis, an inquiry teaching model is established, which aims to optimise all aspects of inquiry teaching, including the determination of learning objectives, the allocation of learning resources, the organisation of learning activities and the evaluation of learning effects, by deeply analysing the key nodes, group relations and information dissemination paths in social networks. Through this model, it is expected to give full play to students' initiative and improve their learning effect and social skills.

2.3.1 Determination of learning objectives

According to the results of social network analysis, combined with the course content and the actual situation of students, the specific learning objectives are determined.

2.3.1.1 Understand the results of social network analysis

Need to deeply understand the results of social network analysis. This includes identifying key nodes (that is, students who occupy an important position in the network), group structure (that is, different groups formed by social interaction between students) and information dissemination path (that is, the path through which information flows among students). These analysis results provide valuable information about the interaction mode between students, so as to deeply analyse the learning characteristics and needs of students.

2.3.1.2 Combined with the course content

After determining the results of social network analysis, it is necessary to combine this information with the course content. By analysing the course content, we can make clear

the learning goals that students need to achieve, and determine the teaching activities and resources needed to achieve these goals.

2.3.1.3 Consider the actual situation of students

In addition to the results of social network analysis and course content, it is also necessary to consider the actual situation of students, which is helpful to better formulate learning goals that meet their needs. For example, for students at key nodes, more challenging and high-level learning goals are tailored for them to further stimulate their potential and enhance their comprehensive ability; for students with weak foundation, we can set more basic learning goals for them and provide more support and help.

2.3.1.4 Develop personalised, differentiated and hierarchical learning objectives

After comprehensively considering the results of social network analysis, course content and students' actual situation, we can start to formulate relevant teaching objectives, the specific contents are as follows:

- Individualisation: learning objectives should be set according to the specific situation of each student to meet their individual needs. For example, for students who like to explore, more exploration tasks can be designed for them; for students who like to cooperate, more team activities can be organised for them.
- Differentiation: in view of the diversity of students' hobbies, study habits and cognitive styles, the principle of individuality should be embodied in educational practice. Tailor-made unique learning goals for each student can not only better meet their learning needs, but also effectively stimulate their learning enthusiasm and internal motivation.
- Hierarchical: the setting of learning objectives should follow the principle of hierarchy, from basic foundation to advanced proficiency, step by step, to guide students to gradually deepen their mastery of knowledge and skills. This design aims to provide students with step-by-step challenges and continuous incentives to ensure their steady progress on the road of learning. Learning objectives can be divided into multiple levels, and clear evaluation criteria can be set for each level, so as to accurately evaluate students' learning achievements and give timely feedback.

2.3.2 Allocation of learning resources

According to the characteristics and group relationship of key nodes, the learning resources are allocated reasonably. For key nodes, more abundant and in-depth learning resources should be provided to support their learning needs. At the same time, we should pay attention to the sharing and exchange of learning resources within and between groups in order to promote the effective dissemination of information.

2.3.2.1 Identify key nodes and allocate rich resources

Social network analysis can reveal the key nodes that occupy an important position in the network. These students often have significant influence in information dissemination and opinion leaders. For these key nodes, we should provide more abundant and in-depth

learning resources to meet their higher learning needs and play their positive role in the learning community.

- Advanced learning materials: provide more challenging and in-depth learning materials for key nodes, such as advanced tutorials, professional books, online courses, etc., to stimulate their learning potential and interest.
- Expert guidance: provide professional tutors or domain experts for key nodes in order to solve the problems they encounter in the learning process.
- Priority access: In the case of limited resources, such as laboratory equipment, library scarce books, etc., key nodes can be given priority access to ensure that they can obtain the required learning resources.

2.3.2.2 Pay attention to resource sharing within and between groups

Besides paying special attention to key nodes, we should also pay attention to the sharing and communication of learning resources within and between groups. By promoting the effective dissemination and utilisation of resources, the overall learning effect can be improved.

- Establish a sharing platform: create an online platform or learning community to allow students to upload and share their own learning resources, such as study notes, courseware, project cases, etc. In this way, students in the group can learn from each other, learn from each other and supplement each other, so as to maximise the use of resources.
- Promote inter-group communication: encourage students from different groups to communicate and interact, so as to promote the cross-group communication of information. You can organise cross-group learning seminars, project cooperation and other activities, so that students have the opportunity to contact and learn the knowledge and experience of different groups.
- Set up a resource recommendation mechanism: set up a resource recommendation mechanism in the learning community so that students can recommend learning resources that they think are valuable.

2.3.2.3 Evaluate and adjust resource allocation regularly

The allocation of learning resources is a dynamic process, which needs to be adjusted with the changes of students' needs and learning situation. Students' learning progress and resource use should be evaluated regularly, and resource allocation should be adjusted and optimised according to the evaluation results.

- Collect feedback: collect students' feedback on the allocation of learning resources in various ways to understand their needs and expectations.
- Data analysis: use social network analysis and other tools to analyse students' learning behaviour and interaction, so as to find potential problems and improvement points.

- Adjustment strategy: according to the collected feedback and data analysis results, adjust and optimise the allocation strategy of learning resources in order to improve the teaching quality to the greatest extent.

Through the implementation of the above measures, we can realise more accurate and effective allocation of learning resources and provide strong support for students' learning. At the same time, it can also promote the effective dissemination and sharing of information among students and improve the overall learning effect.

2.3.3 Learning activity organisation

In the organisation of learning activities, we should make full use of the laws of information dissemination paths. For example, students can be guided to explore knowledge and solve problems along the information dissemination path by setting appropriate inquiry tasks.

2.3.3.1 Organising learning activities by using information transmission paths

Identify the information transmission path: through social network analysis, the information transmission path between students can be clearly identified. These paths not only reveal the flow of information, but also reflect the knowledge sharing and interaction mode among students.

- Designing inquiry tasks: based on information dissemination paths, teachers can design a series of inquiry tasks to guide students to explore knowledge and solve problems along these paths.
- Optimise the task flow: in the task design process, teachers can optimise the task flow according to the efficiency and accuracy of the information transmission path. For example, students at key nodes can be given more responsibilities and roles to promote the rapid dissemination of information and effective feedback.

2.3.3.2 Organise group study and discussion based on group relationship

Identify the group structure: social network analysis can reveal the group structure among students, and these groups are often formed based on common interests, learning styles or social relationships.

- Organise group learning: teachers can organise group learning according to the characteristics of group structure. Combining students with similar characteristics can improve the cohesion and cooperation efficiency of the group. At the same time, it can also promote exchanges and interactions between different groups and broaden students' horizons and ideas.
- Guide discussion and communication: in the process of group learning, teachers should actively guide students to discuss and communicate, so as to cultivate critical thinking and innovative ability.

2.3.3.3 Pay attention to the interaction and feedback during the activity

- Observing student interaction: in the process of organising learning activities, teachers should pay close attention to the interaction between students, and these observations can provide valuable information for teachers to adjust teaching strategies and methods in time.
- Collect students' feedback: after the activity, teachers can collect students' feedback through questionnaires and individual interviews. Understand students' views and suggestions on activity organisation, task design and resource allocation, so as to continuously improve and optimise teaching activities.

In a word, taking advantage of the characteristics of information dissemination path and group relationship through the organisation of learning activities can greatly improve students' learning experience and effect.

2.3.4 Evaluation of learning effect

In the process of teaching, evaluating students' learning effect regularly is a key step to ensure the teaching quality and the achievement of learning goals. The assessment methods need to be diversified to comprehensively and accurately reflect students' learning achievements. At the same time, in view of the social interaction in modern learning environment, it is also essential to evaluate students' social network performance. The following is a detailed expansion of this content:

2.3.4.1 Diversified evaluation methods

- Testing: in the field of evaluating students' learning effectiveness, the traditional written test and oral test still occupy a decisive position. These two evaluation methods can not only deeply test students' memory and understanding of knowledge, but also evaluate students' knowledge application ability and problem-solving ability through practical application scenarios. Teachers can design topics with different difficulties and types to comprehensively evaluate students' learning achievements.
- Questionnaire survey: through questionnaire survey, teachers can collect students' feedback on course content, teaching methods and learning resources, and teachers will adjust teaching strategies according to the feedback.
- Observation: observation is an intuitive way to evaluate students' learning effect. Teachers can evaluate students' learning in an all-round way by observing their performance in class, their participation in discussions and the progress of completing tasks.

2.3.4.2 Diversification of evaluation indicators and innovation of evaluation methods

Exploratory teaching mode is a student-centred teaching method that encourages students to actively learn by asking questions, conducting surveys and experiments, analysing data, and building knowledge. Evaluating the effectiveness of exploratory teaching mode requires a specific set of indicators that can reflect students' participation, critical

thinking ability, problem-solving skills, and knowledge mastery in the exploration process. Diversified evaluation indicators are as follows:

- Participation: the quantity and quality of questions raised by students; the activity level of students in group discussions and class discussions; the time and frequency of student participation in experiments, surveys, and projects.
- Critical thinking and problem-solving: students analyse and evaluate the depth and breadth of information; the ability of students to propose and verify hypotheses; strategies and methods for students to solve complex problems.
- Self directed learning ability: the ability of students to conduct independent research and learning; the ability of students to self monitor and adjust their learning process; Students' ability to use resources (such as libraries and the internet) for learning.
- Collaboration and communication: students' contributions and leadership skills in group collaboration; the ability of students to express their thoughts and opinions clearly and effectively; the ability of students to listen and respect the opinions of others.
- Knowledge mastery and application: students' understanding and mastery of the exploration topic; The ability of students to apply their learned knowledge to new situations; Students have the ability to explain and summarise the results of their research.
- Reflection and metacognition: students' reflection and self evaluation of the learning process; students' ability to identify their strengths and areas for improvement in learning; the ability of students to set learning goals and plans.
- Creativity and innovation: students' ability to propose innovative ideas and solutions; the creative thinking demonstrated by students during the exploration process; students' ability to design and implement innovative projects.

In the evaluation process of inquiry based teaching mode, there are various innovative evaluation methods aimed at comprehensively and objectively assessing students' learning effectiveness and teachers' teaching quality

1 Combining formative evaluation with summative evaluation

- a Formative evaluation: an evaluation that runs through the entire learning process, aimed at timely understanding students' learning progress and existing problems, so that teachers can adjust teaching strategies and promote better learning for students. This evaluation method focuses on students' performance and progress in the learning process, and can be conducted through classroom observation, learning logs, group discussions, and other methods.
- b Summative evaluation: a summary evaluation conducted after the end of the learning phase, mainly examining students' learning outcomes and achieved teaching goals. Although summative assessment plays an important role in traditional education, in inquiry based teaching models, it should be combined with formative assessment to more comprehensively reflect students' learning situation.

2 Performance evaluation

Evaluate students' learning outcomes by observing their performance in completing practical tasks. This method emphasises the application of knowledge and skills, relying on specific real-life tasks, and can more accurately reflect students' true level. Teachers can design a series of expressive tasks related to the course content, such as experiments, projects, presentations, etc., to allow students to demonstrate their knowledge and skills while completing the tasks. Then, evaluate the students based on their performance in the task.

3 Archive bag evaluation

A way of evaluating students' learning process and achievements by collecting materials such as student works, learning records, reflection reports, etc. The materials in the portfolio not only reflect students' learning outcomes, but also their efforts, progress, and reflection during the learning process. Teachers and students jointly establish a portfolio, regularly collect students' learning works, reflection reports, and other materials, and organise and display them. Through portfolio evaluation, teachers can have a more comprehensive understanding of students' learning situations, and students can also have a better understanding of their own learning processes and achievements.

4 Peer evaluation and self-evaluation

- a Peer evaluation: students evaluate each other's learning outcomes and performance. This approach can enhance students' sense of participation and responsibility, while promoting communication and cooperation among them.
- b Self evaluation: students reflect and evaluate their learning process and outcomes. Through self-evaluation, students can have a clearer understanding of their strengths and weaknesses, and thus develop more reasonable learning plans and goals.

5 Digital evaluation tool

With the development of technology, more and more digital evaluation tools are being applied in teaching, such as online testing platforms, learning analysis software, etc. These tools can quickly collect and analyse students' learning data, providing teachers with timely and accurate feedback information. At the same time, they can also provide personalised learning advice and feedback to students, promoting their self-directed learning and development.

In summary, there are various innovative evaluation methods in the evaluation process of inquiry based teaching mode. These methods not only help to comprehensively and objectively evaluate students' learning outcomes and teachers' teaching quality, but also promote students' self-directed learning and comprehensive development.

2.3.4.3 Pay attention to the performance in social networks

- Participation: in social networks, students' participation is one of the important indicators to measure their learning effect. Teachers can evaluate students' participation and enthusiasm for learning by observing the number of speeches, the

quality of responses and the depth of discussion in social networks such as online discussion forums, learning communities and collaborative platforms.

- **Contribution:** the contribution of students in social networks reflects their contribution and value to the learning community. Teachers can evaluate students' contribution and learning achievements by observing the learning resources shared by students, innovative ideas put forward and solutions to problems.
- **Interactive ability:** interactive ability in social networks is an important indicator to measure students' social skills. Teachers can evaluate students' interaction ability and social skills by observing their interaction style, communication skills and teamwork ability in social networks.

2.3.4.4 Comprehensive evaluation and feedback

- **Comprehensive analysis:** after collecting all kinds of evaluation data, teachers need to comprehensively and accurately evaluate students' learning effect by analysing test scores, questionnaire survey results, observation records and performance in social networks.
- **Provide feedback:** based on the evaluation results, teachers should provide timely feedback to students. In order to motivate students with different performance levels, differentiated strategies should be adopted. For students with outstanding performance, we should give them positive feedback and appropriate rewards without stint, so as to encourage them to continue to maintain excellent learning status. For students who encounter challenges in their studies, they should provide more targeted guidance and suggestions to help them find the root of the problem and provide solutions.
- **Continuous improvement:** the evaluation of learning effect is a continuous process. In the teaching process, teachers should constantly collect and analyse evaluation data, and constantly improve teaching methods and resource allocation strategies according to the evaluation results, so as to improve teaching quality and learning effect.

3 Implementation of inquiry teaching model based on social network analysis

3.1 Executive plan

The implementation scheme of inquiry teaching mode based on social network analysis aims to construct an inquiry learning environment with students as the main body and teachers as the guide by combining the theory and methods of social network analysis. Teachers evaluate students' learning effect according to the requirements of teaching objectives and inquiry tasks. Collect teaching data through tests, questionnaires and observation records, so as to fully understand students' learning achievements and social network performance. The specific experimental data types are shown in Table 2.

Integrate the obtained data into a dataset, divide the dataset into a test set and a training set, input the data from the test set into computer software for training,

continuously calculate the optimal operating parameters of the software, and use these parameters as the initial parameters for subsequent experiments to ensure the accuracy of the experimental results.

Use the Cai and Hu (2023) method, Chen et al. (2020) method, and the proposed method as experimental comparison methods to compare the achievement rate of inquiry based teaching objectives, learning participation rate, and student academic performance of different methods.

Table 2 Experimental data types

<i>Data type</i>	<i>Amount of data</i>
Basic student information data	6.33GB
Learning behaviour data	8.96GB
Social network data	10.32GB
Evaluation data	4.85GB
Teaching resource data	6.41GB
Reflection and feedback data	4.47GB

The achievement rate of teaching objectives refers to the ratio of students' actual completion of teaching objectives to the preset teaching objectives, usually expressed in percentage form. It reflects the students' mastery of knowledge, improvement of abilities, and development of emotional attitudes and values during the teaching process. It is mainly measured through various methods such as direct observation, Q&A interaction, test evaluation, and project presentation.

Learning participation rate refers to the ratio of the number of students who actually participate in learning activities to the total number of students during the learning process, usually expressed in percentage form. It covers students' behaviours such as interaction, discussion, questioning, and answering in the classroom, as well as their self-directed learning, homework completion, and participation in group projects after class. It is mainly measured through classroom observation, learning logs or reflection reports, online learning platform data, and other methods.

The academic achievement improvement index is mainly used to measure the magnitude or rate of improvement in students' academic performance during the learning process, especially within a specific learning cycle. It is mainly measured through various methods such as exams, tests, homework evaluations, self-evaluation, and peer evaluations.

3.2 Experimental result

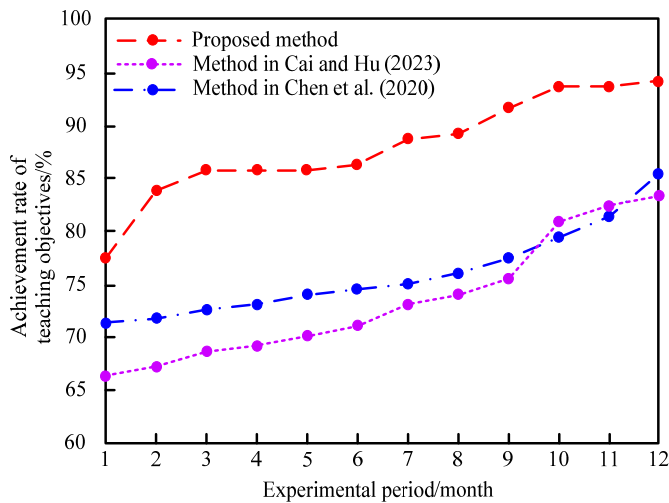
3.2.1 Achievement rate of exploratory teaching objectives

The achievement rate of exploratory teaching objectives under the application of Cai and Hu (2023) method, Chen et al. (2020) method, and the proposed method is shown in Figure 1.

By analysing the data in Figure 1, it can be seen that with the continuous improvement of the experimental period, the achievement rate of exploratory teaching goals under the application of the three methods shows an upward trend, indicating that these three methods can promote the achievement of exploratory teaching goals.

However, with a 12 month experimental period, the achievement rates of the three methods of inquiry based teaching objectives reached their maximum values. Among them, the maximum achievement rate of inquiry teaching objectives under the application of Cai and Hu (2023) method is 82.5%, the maximum achievement rate of inquiry teaching objectives under the application of Chen et al. (2020) method is 83.9%, and the maximum achievement rate of inquiry teaching objectives under the application of the proposed method is 93.1%, which is 10.6% and 9.2% higher than the Cai and Hu (2023) method and Chen et al. (2020) method, respectively. This indicates that compared with the experimental comparison method, the proposed method can effectively improve the achievement rate of inquiry teaching objectives and promote the achievement of multiple inquiry teaching objectives.

Figure 1 Achievement rate of exploratory teaching objectives (see online version for colours)

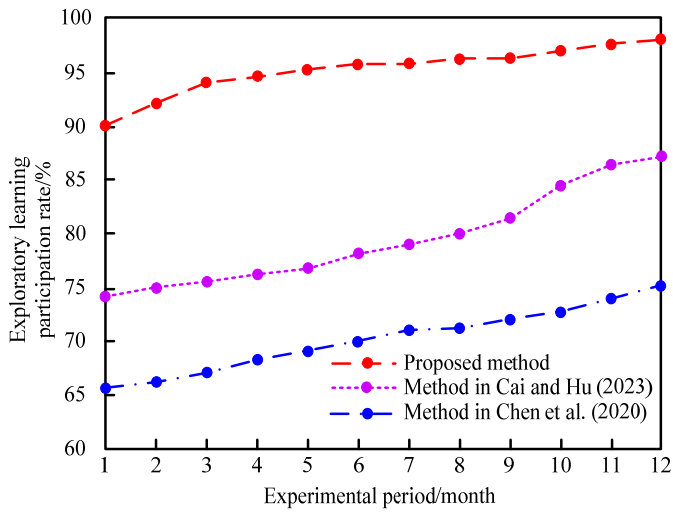


3.2.2 Learning participation rate

The participation rate of exploratory learning under the application of Cai and Hu (2023) method, Chen et al. (2020) method, and the proposed method is shown in Figure 2.

Analysing the results in Figure 2, it can be seen that as the experimental period continues to increase, the participation rate of exploratory learning under the application of the three methods shows an upward trend, indicating that all three methods improve the participation rate of exploratory learning. When the experimental period reaches 12 months, the participation rates of exploratory learning for all three methods reach their maximum values. Among them, the maximum participation rate of inquiry learning under the Cai and Hu (2023) method application is 86.7%, the maximum participation rate of inquiry learning under the Chen et al. (2020) method application is 74.2%, and the maximum participation rate of inquiry learning under the proposed method application is 97.2%, which is 10.5% and 23.0% higher than the Cai and Hu (2023) method and the Chen et al. (2020) method, respectively. This indicates that compared with the experimental comparison method, the proposed method can effectively improve the participation rate of inquiry learning, and the actual application effect is good.

Figure 2 Participation rate of exploratory learning (see online version for colours)



3.2.3 Student academic performance

Cai and Hu (2023) method, Chen et al. (2020) method, and the academic achievements of the proposed methods are shown in Table 3.

Table 3 Student academic performance under different method applications

Experimental period/month	Under the application of Cai and Hu (2023) method	Under the application of Chen et al. (2020) method	Application of the proposed method
1	60.3	70.3	70.3
2	60.8	71.4	75.2
3	61.1	72.5	76.1
4	61.8	73.8	78.8
5	62.4	74.1	78.3
6	63.6	74.9	79.9
7	64.1	75.4	80.3
8	64.8	76.8	82.7
9	65.9	77.2	86.6
10	66.4	78.3	87.2
11	67.7	78.6	89.4
12	68.9	78.8	90.2

According to the analysis of the results in Table 2, it can be seen that the academic performance of students under different method applications increases with the continuous increase of the experimental period. Among them, when the experimental period reached 12 months, the student's academic performance reached its maximum value. Among them, the maximum academic performance of students under the Cai and Hu (2023) method application is 68.9, the maximum academic performance of students

under the Chen et al. (2020) method application is 78.8, and the maximum academic performance of students under the proposed method application is 90.2, which is 21.3 and 11.4 higher than the Cai and Hu (2023) method and the Chen et al. (2020) method, respectively. This indicates that the inquiry based teaching strategy under the proposed method application can effectively improve student academic performance and achieve the expected goals.

4 Conclusions

At present, the construction and implementation of inquiry teaching mode has become one of the important directions of education reform, so this paper mainly studies the construction and implementation of exploratory teaching model based on social network analysis. The experimental results show that the maximum achievement rate of inquiry teaching goal, the maximum participation rate of inquiry learning and the maximum academic achievement of students are 93.1%, 97.2% and 90.2, respectively, and the practical application effect is good. Through the application of inquiry teaching mode, we hope to promote the in-depth development of educational reform and improve the quality and efficiency of education. The research on the construction and implementation of inquiry based teaching mode based on social network analysis is of great significance for improving teaching quality and effectiveness, enhancing learning participation and cooperation ability, promoting innovation and development of teaching mode, and promoting educational equity and inclusiveness. Future research can expand the application areas of inquiry based teaching models. In addition to traditional natural science disciplines, inquiry based teaching models can also be applied to fields such as social sciences and humanities. By expanding the application areas, the advantages and value of inquiry based teaching mode can be further leveraged.

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