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Original Article

Integrating Diversified Graphical Thinking Mode into the Teaching Practice of Inorganic Chemistry

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ABSTRACT

Background: Inorganic chemistry holds significant importance in pharmacy major as it serves as the foundation for subsequent professional courses. However, students exhibit varying learning conditions during the teaching process, with some struggling due to weak knowledge of chemistry. **Objectives:** To enhance the quality of teaching and learning outcomes, foster logical thinking skills and independent learning abilities among students and further promote the exploration and implementation of reforms in inorganic chemistry education. This study aims to integrate diverse graphical thinking modes into inorganic chemistry teaching practices, guiding students to simplify and visualize knowledge through graphical thinking. **Materials and Methods:** Based on the course design, various diversified graphic thinking modes are introduced into teaching practices, followed by a comparative analysis and questionnaire survey to evaluate their impact on teaching effectiveness and student satisfaction. **Results:** The experimental group achieved an average score of 12.1 points higher than that of the control group ($p<0.01$). Moreover, satisfaction surveys reveal significantly higher levels of satisfaction among 96.4% of students from the experimental group compared to 83.6% from the control group using traditional teaching methods ($p<0.05$). Additionally, a survey assessing acceptability among students in the experimental group yielded satisfactory responses ranging from 81.8-94.5% across all 10 questions. **Conclusion:** Incorporating diversified graphical thinking modes into the inorganic chemistry teaching process can improve academic performance and interest while enhancing overall teaching effectiveness, thus providing valuable insights for developing diversified instructional approaches.

Keywords: Graphic thinking mode, Inorganic chemistry, Teaching strategy, Chemical teaching, Higher education.

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INTRODUCTION

The study of inorganic chemistry is an essential component of the curriculum for freshmen pursuing pharmacy major in medical colleges. It serves as a fundamental basis for students to delve into other specialized courses. The course primarily focuses on imparting knowledge regarding key concepts, principles and practical applications of inorganic chemistry that are relevant to the field of medicine.

Through preliminary investigation and feedback on the teaching process, it has been observed that the students' learning background in high school chemistry courses is multifaceted. In China, students from different regions exhibit varying levels of proficiency in chemistry fundamentals, with some displaying relatively weak knowledge and low interest in learning, leading to numerous challenges encountered during the study of inorganic chemistry. Simultaneously, students encounter the transition in pedagogical approaches at the tertiary level, thereby intensifying the complexity of their learning experience. To comprehensively improve the teaching effect of inorganic chemistry courses, optimize academic performance, foster logical reasoning skills and cultivate independent learning capabilities among students, it is imperative to adapt and refine the teaching methodology employed for inorganic chemistry to ensure superior instructional quality.[2]

Illustration serves as a crucial tool for presenting core knowledge in chemistry education, including mind maps, flow charts, experimental setup diagrams, coordinate diagrams, molecular structure diagrams, model diagrams and so on. Graphical thinking represents a tangible form of cognition that has been demonstrated to stimulate learning interest, foster students' learning engagement, facilitate their mastery of fundamental concepts and promote a profound understanding of the essence of chemistry.[3] Integrating the diversified graphic thinking mode into

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the teaching process of inorganic chemistry will provide a novel and effective model for curriculum reform that aligns with the demands of contemporary development. Within this pedagogical approach, instructors employ a graphical thinking teaching method to visually represent extensive information through pictures and illustrations, thereby rendering abstract content more visualized and intuitive.[4] By conveying textual information graphically, students can easily comprehend and apply it within their learning journey due to its clear organization. Through the observation and analysis of diagrams, students can enhance their development of graphical thinking, enabling them to effectively acquire, assimilate and integrate knowledge. Consequently, they will be able to improve their information retrieval skills as well as their abilities to analyze and solve problems. This will provide a solid foundation for their subsequent study of relevant professional courses.

In this study, a diversified graphical thinking mode was introduced into the teaching process of inorganic chemistry and implemented throughout the entire instructional practice. Various types of diagrams were integrated into multimedia courseware, enabling students to engage in graphical thinking during pre-class preparation, post-class review, classroom discussions, communication and learning activities. The utilization of diversified graphical thinking modes also facilitates students in simplifying and visualizing complex knowledge through graphical representation. Additionally, the effectiveness of employing diverse graphical thinking modes in teaching inorganic chemistry was assessed based on student feedback during class and changes in final grades. The course design of inorganic chemistry has been optimized to facilitate the further exploration and implementation of teaching reforms in this field. The methods and patterns are implemented according to the technical roadmap depicted in Figure 1.

MATERIALS AND METHODS

Teaching design and practice

The first chapter of the textbook utilized in this course serves as an introductory section on inorganic chemistry, while each subsequent chapter starting from Chapter 2 can be effectively taught using the graphical thinking teaching method. By incorporating diverse forms of graphical thinking into the instructional framework of inorganic chemistry courses, students can realize a rapid transformation in their learning mode upon entering college, thereby enhancing their attentiveness during lectures, fostering a greater interest in learning and reinforcing the efficacy of post-class review sessions. Consequently, they can acquire knowledge more efficiently and solidly. Simultaneously, this pedagogical approach cultivates students' awareness and capacity for independent learning while stimulating their intrinsic motivation to learn. Diagrams encompass various formats such as mind maps, model diagrams, flow charts, experimental setup diagrams and molecular structure diagrams (Figure 2). In conjunction with the teaching content of inorganic chemistry, the following presents the application of various graphic thinking modes within the teaching process.

Application of mind map throughout the entire course teaching process

The mind map, initially proposed by Tony Buzan, a renowned British psychologist, serves as a comprehensive and radiant expression of divergent thinking.[5] It represents an essential tool for knowledge summary and enhancement of students' learning efficiency.[6,7] By employing visual elements such as graphics, lines, symbols and colors in form, the mind map constructs a knowledge tree that organizes intricate thoughts based on hierarchical relationships among themes. Consequently, it makes the boring content vivid, intuitive and orderly.[8] This approach facilitates the establishment of holistic and logical concepts during the process of knowledge acquisition while aiding students in memory, comprehension and thinking. The primary advantage of a mind map lies in its function of summarizing a vast amount of trivial and complex textual information into a single diagram, effectively interconnecting various knowledge points within a chapter, forming a comprehensive understanding of knowledge, establishing a systematic framework for thinking and ultimately enabling students to construct a scientific and rational knowledge structures network.[9]

To enhance the clarity of knowledge points within a chapter and illustrate their interrelationships, as well as enable students to obtain a comprehensive understanding of a chapter, the content and knowledge framework can be effectively presented through the mind maps. As the course progresses, this approach extends beyond teacher-guided induction and summarization, encouraging students to independently finish mind maps before and after class. This practice facilitates their mastery of textbook content, deepens comprehension and increases capacity and interest in independent learning. Taking the example of "Buffer solution", as depicted in Figure 3, a mind map can enable students to comprehend the core content encompassing definition, principle, calculation, preparation and application of buffer solutions through only a single diagram, which helps students to clarify logical connections logic and get the key points.

Application of model diagrams to microchemical structures

Chemical structure is one of the important and difficult problems to understand in the inorganic chemistry course. The study of inorganic chemistry usually involves intricate microchemical structures, demanding students to possess a certain level of imaginative ability.[10] In previous teaching methods, the complex content was typically conveyed through verbal explanations and limited blackboard illustrations, which presented challenges and difficulties to learn for students with weaker foundations. To enhance the comprehension of students and make the teaching process more engaging, it is beneficial to employ model diagrams that vividly depict the microscopic structures and dynamic motion states of cells, molecules, atoms and other substances; thus, rendering abstract concepts more tangible. Consequently, it becomes imperative to deepen students' understanding while cultivating their visual literacy skills.

As shown in Figure 4, in the chapter on *dilute solution dependence*, the morphological models help students understand the direction of solvent penetration of red blood cells in hypertonic, hypertonic and hypotonic solutions with varying concentrations, as well as their medical applications. When red blood cells are placed in a dilute NaCl solution (e.g., 3.0 g/L), water enters the erythrocytes causing continuous expansion. Microscopic observation reveals the rupture of red blood cells and release of hemoglobin, facilitating comprehension of this medical phenomenon known as "hemolysis". Conversely, when red blood cells are exposed to a concentrated NaCl solution (e.g., 15.0 g/L), the osmotic pressure inside erythrocytes becomes lower than that in extracellular fluid leading to water seepage from within and gradual crumpling. Under microscopic examination, clustered crumpled erythrocytes can be observed forming groups which may result in "embolism" if occurring within blood vessels.

Another example, the ion absorption theory is one of the classical theories in the field of strong electrolyte solution discussed in the Chapter on *Strong electrolyte solution theory*. It introduces the concept of "ion atmosphere", which may pose challenges for beginners to comprehend. To address this issue, Figure 5 illustrates a model diagram depicting the ion atmosphere, which can be effectively integrated into multimedia courseware and animated during teaching processes to facilitate better understanding and visualization of complex concepts. Empirical evidence from teaching practices has demonstrated that students readily accept the existence of the ion atmosphere model, thereby enhancing their comprehension and mastery of this particular part.

Application of flow charts in the chemical course

The flow chart can clearly and precisely illustrate the processes of chemical reactions or biological activities.[11] The human body functions as a complex system of chemical reactions, constantly undergoing various forms of material metabolism and energy changes. Flow charts are effective visual tools for representing chemical, biochemical reactions, or chemical production processes. During flow chart analysis, it is essential to fully comprehend the sequence of substance transformations and separations throughout the entire process, further comprehensively clarifying the transformational pathways of substances.[12,13] Understanding the buffering principle is crucial yet challenging in studying the chapter on *buffer solution*, so flow charts are employed to explain to students in the course of teaching. As depicted in Figure 6, slide animations demonstrate how buffer solutions act as buffers

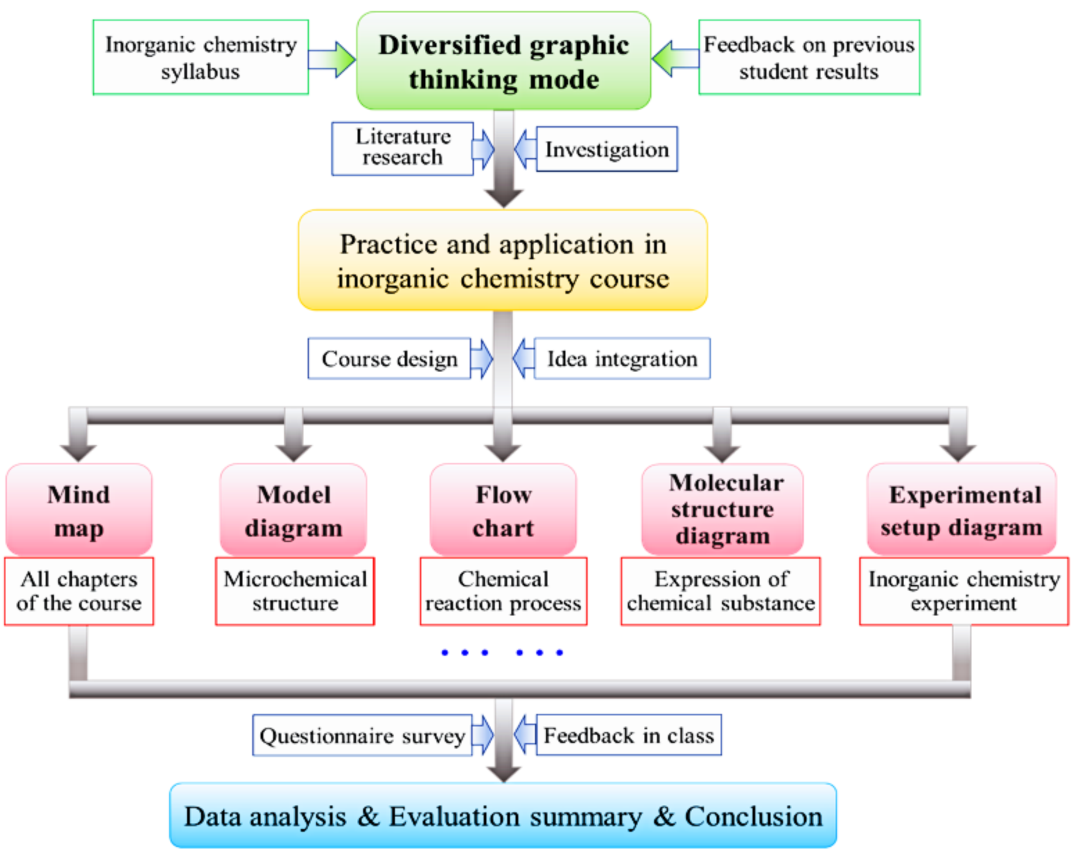

Figure 1: The overall roadmap of study.

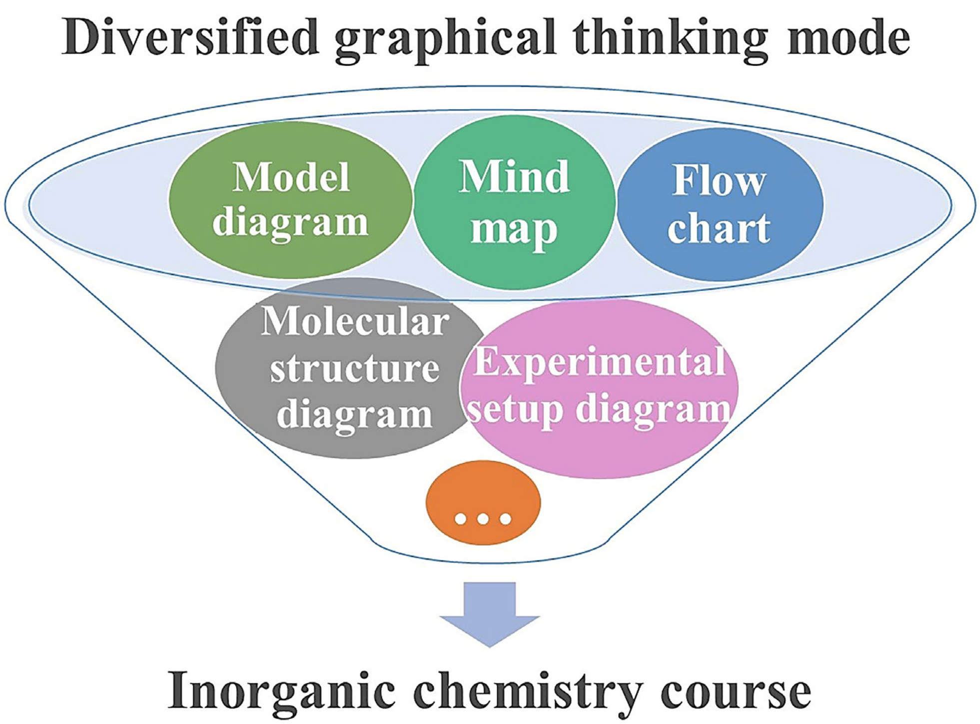

Figure 2: Diversified graphical thinking mode.

when small amounts of acid or base are added. In the HAc-NaAc buffer solution, the addition of a small quantity of H^+ causes a leftward shift in the dissociation equilibrium of HAc, resulting in minimal change in H^+ concentration and thereby demonstrating negligible alteration in pH value. Consequently, it is evident that this buffer solution exhibits resistance against minute amounts of strong foreign acids while maintaining its pH value essentially unaltered. Teaching practice shows that students gain a better understanding of buffer solution principles through learning this content using flow charts.

Another example is the crucial role of buffer pairs in maintaining the acid-base balance within the human body. The human body functions as an extensive buffer system, with the buffer pairs of H_2CO_3-$NaHCO_3$ in plasma playing a vital role in this equilibrium. However, when the buffering mechanism is explained, students often struggle to comprehend why the buffering ratio of HCO_3^--H_2CO_3 in the human body is only 20:1, yet it effectively resists external acids or bases while maintaining a stable pH range. By presenting a flow chart instead of relying solely on traditional explanations for chemical equations, students can gain clearer insights into the process and principles underlying buffering mechanisms. As depicted in Figure 7, being an "open system", the human body exhales carbon dioxide through respiration from the lungs to remove acid (H_2CO_3) in the body, to counteract foreign acid. Simultaneously, alkaline HCO_3^- ions are excreted by kidneys to combat foreign bases. This visual representation combined with interactive flash animation facilitates students' comprehension of this point.

Application of molecular structure diagram in representing chemical substances

The molecular structure diagram is a type of graphical representation that depicts the spatial arrangement of atoms within a molecule. The molecular structure plays a crucial role in determining the reactivity, polarity, phase state, magnetism and biological activity of chemical substances. Therefore, understanding the molecular structure is essential for comprehending the properties of compounds.[14] The molecular structure encompasses atom positions in space and is closely related to various factors such as chemical bonding types, bond lengths, bond angles and dihedral angles between adjacent bonds. Professional chemical software like Chemdraw and 3D Max can be employed to generate diverse forms of molecular structure diagrams. These ways not only stimulate students' curiosity towards novel concepts but also enhance their self-directed learning initiative, further facilitating a deep comprehension of compound structures. Moreover, they lay the foundation for subsequent exploration into chemical properties. For instance, coordination compounds are often unfamiliar and challenging for most students due to limited exposure during previous studies.[15] By incorporating illustrations into teaching processes and employing molecular structure diagrams to depict ligand and complex structures explicitly while concretizing coordination bonds, it becomes easier to elucidate how ligands connect with the central atom (as shown in Figure 8 where ethylenediamine acts as the ligand while N serves as the coordination atom). Each ethylenediamine molecule can establish two coordination bonds with the central ion Co^{3+}, while Co^{3+} can form chelates by coordinating with three ethylenediamine molecules through six coordination bonds. This intuitive yet accurate presentation significantly improves students' acceptance of new concepts.

Application of experimental setup diagram in inorganic chemistry experiments

The experiment course is an essential component of the inorganic chemistry curriculum, serving as a practical foundation for medical students to engage in future work related to medical inspection and drug testing. During student practice, teachers can rely on concrete thinking modes such as graphic thinking to focus on cultivating students' experimental operation skills and their ability to innovate experimental designs. This integration of theoretical knowledge into the experimental classroom deepens students' understanding and comprehension of theoretical concepts. In the teaching process, the use of experimental setup diagrams directly illustrates equipment connections, substance synthesis, or preparation methods, providing a more intuitive reference for students and facilitating their understanding of experimental principles and mastery of experimental procedures. For instance, titration is a common operation in inorganic chemistry experiments that plays a crucial role in determining food and drug content. Previous experimental teachings have revealed that students lacked scientific placement and reading techniques when using burettes, as well as no proficiency in acid/base burette operations. As illustrated in Figure 9, the arrangement of the burette and conical flask, the essential operation of "dropping with the left hand and shaking with the right hand," as well as the structure and extrusion position of the burette were explained clearly and intuitively for students. The results showed that most students were able to master titration skills after one explanation. Additionally, allowing students to learn how to draw experimental devices using drawing software adds interest to learning while also enhancing their understanding of experimental instruments. Furthermore, encouraging students to use professional chemistry software during active practice can improve the learning effect of the experimental class and lay a solid foundation for subsequent graduation design and scientific research.

Participants

Undergraduate students majoring in Pharmacy at Shenyang Medical College were selected as the research subjects. The control group consisted of students from the 2021 cohort (n=55), while the experimental group comprised students from the 2022 cohort (n=55). There was no significant disparity in admission performance between the two groups and both groups had identical teachers, textbooks and a total of 46 class hours (including 30 theoretical lessons and 16 experimental lessons).

Measures

Both groups were taught using traditional teaching methods. In the teaching process of the experimental group, mind maps, model diagrams, flow charts, molecular structure diagrams and experimental setup diagrams were integrated to facilitate a more intuitive and vivid presentation for students. The teaching process

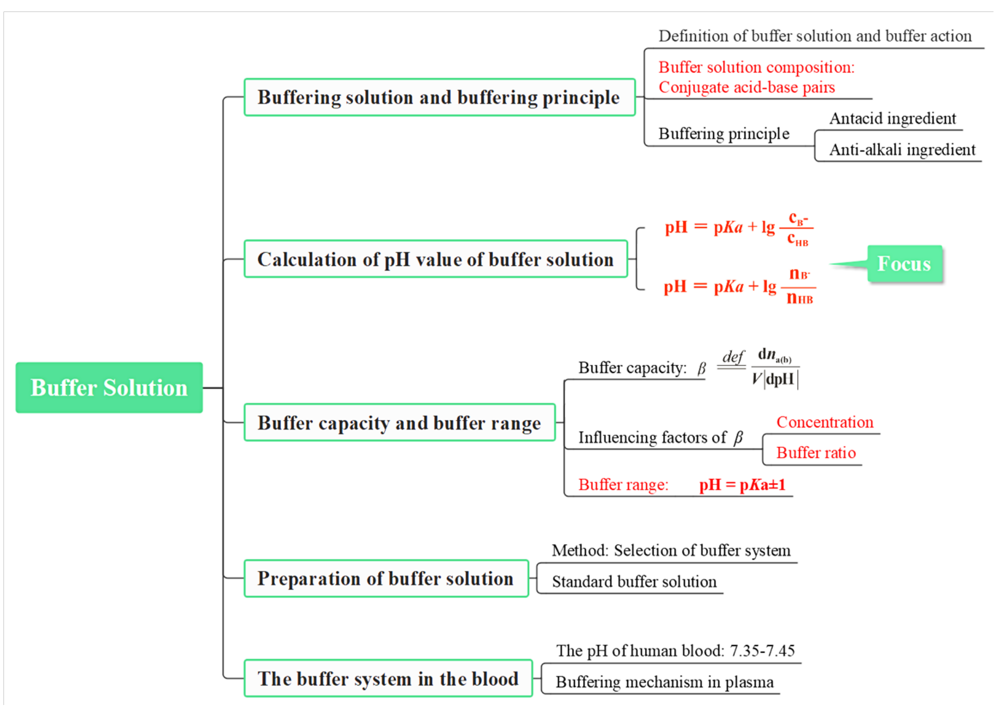

Figure 3: The mind map of the buffer solution.

Table 1: **Analysis of final exam results.**

Groups	Average score*	*t*	*p*
Experimental group	79.2±6.9	4.95	2.8×10^{-6}
Control group	67.1±16.7		

*The maximum score is 100 points.

Table 2: **Analysis of questionnaire results on students' satisfaction.**

Groups	Number of students	Very Satisfied	Satisfied	Dissatisfied	Satisfaction rate
Experimental group	55	47	6	2	96.4%
Control group	55	38	8	9	83.6%
x^2	—	—	—	—	4.95
P	—	—	—	—	0.026

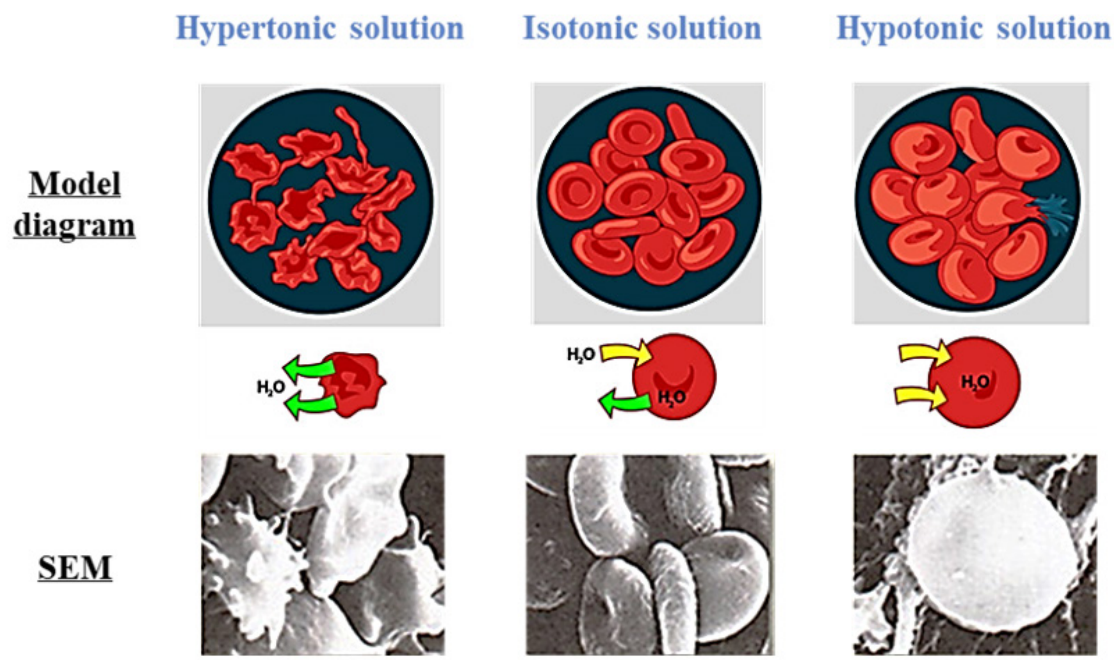

Figure 4: Changes in the morphology of erythrocytes in hypertonic, isotonic and hypotonic solutions.

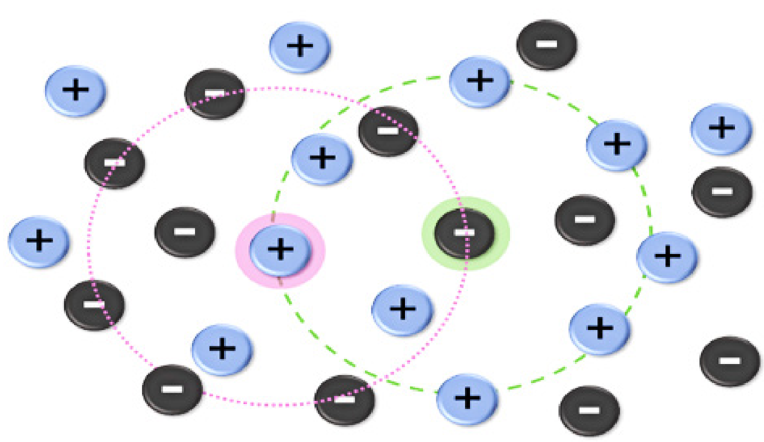

Figure 5: Model diagram of ion atmosphere.

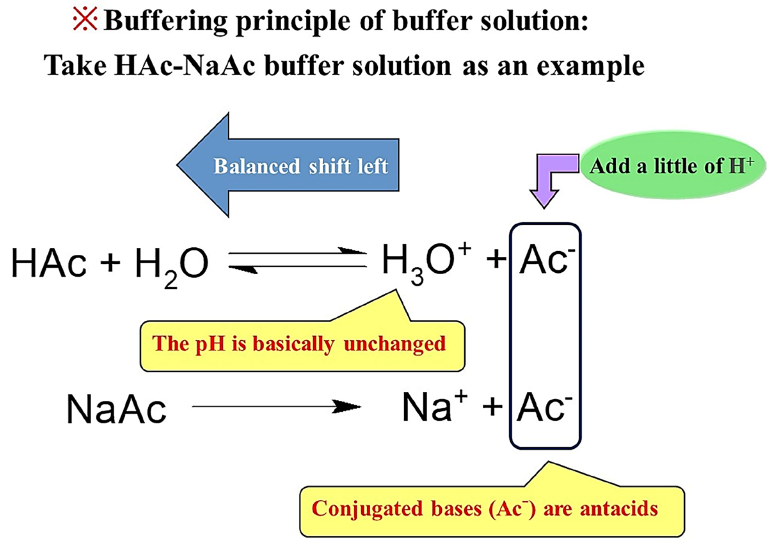

Figure 6: Flow charts of buffering principle for buffer solutions.

Table 3: Questionnaire and results for the experimental group (55 questionnaires were collected).

Sl. No.	Questionnaire content	Number of students choosing "Yes"	Proportion (%)
1	Is it helpful to integrate diversified graphical thinking modes in inorganic chemistry?	50	90.9%
2	Does a mind map help you study in every chapter?	51	92.7%
3	Are model diagrams helpful for understanding abstract concepts and principles in inorganic chemistry theory courses?	49	89.1%
4	Is the flow chart helpful for understanding chemical reactions and production processes?	49	89.1%
5	Whether molecular structure diagrams help to understand and grasp the different representations of chemical substances?	45	81.8%
6	Can drawing a diagram of an experimental setup help you learn in a lab class?	52	94.5%
7	Does the introduction of a graphical thinking mode increase the learning interest in this course?	51	92.7%
8	Whether to improve your ability of independent learning and summary?	49	89.1%
9	Whether the ability to analyze and solve problems has been improved?	47	85.5%
10	Is it broadening the learning mode of chemistry courses?	47	85.5%

of the control group lacked a pedagogical design that integrated multiple modes of graphic thinking. At the end of the course, both the experimental group and control group underwent a final examination consisting of closed-book questions with duration of 90 min. The examination paper was prepared by the same group teachers based on a predetermined plan and outline. The exam comprised multiple-choice questions (20 questions worth 1 point each), fill-in-the-blank questions (10 questions worth 1 point each), short-answer questions (4 questions worth 5 points each) and calculation-based problems (5 questions worth 10 points each). The maximum achievable score was set at 100. All final exam questions for both groups were sourced from the inorganic chemistry question bank of Shenyang Medical College, ensuring a difficulty ratio of 2:5:3 for difficult, medium and easy levels. There was no significant difference in the degree of difficulty in final examinations between the two groups. After the test, the results of the test group and the control group were statistically analyzed. Subsequently, statistical analysis was performed on the test results of both groups, an anonymous questionnaire survey was conducted for all students and the results of the two groups were compared and analyzed to evaluate the implementation effectiveness of the graphic thinking method. Satisfaction

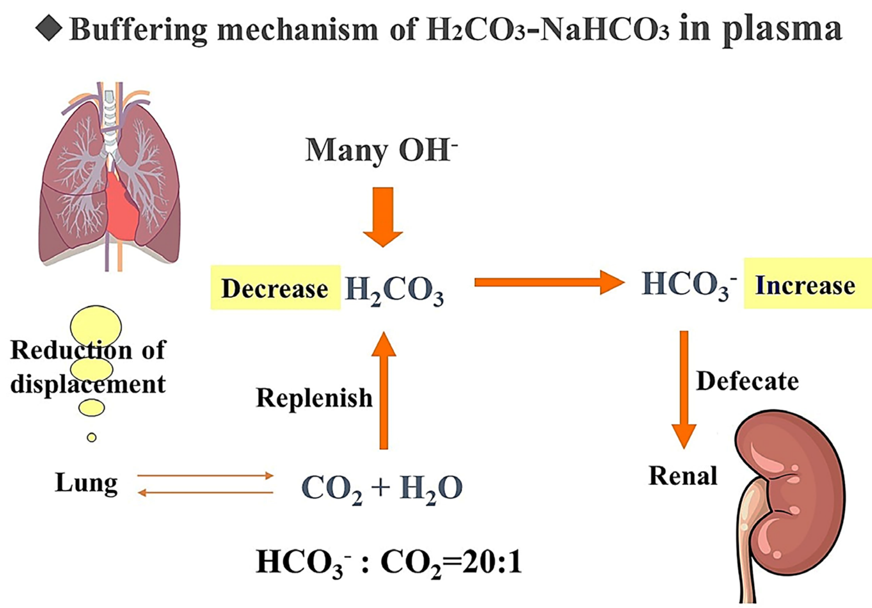

Figure 7: Buffering mechanism of H_2CO_3-$NaHCO_3$ in plasma.

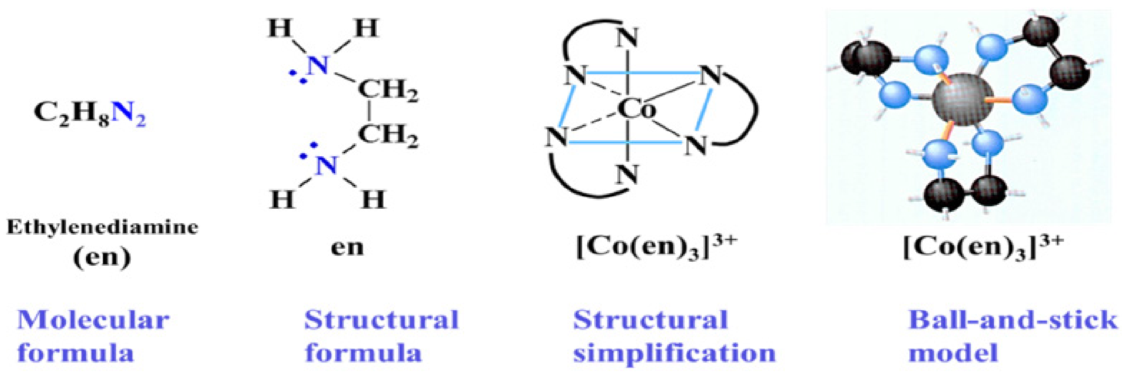

Figure 8: Structure diagrams of ethylenediamine ligands and their complexes.

rate=(very satisfied+satisfied)/total×100%. All participants were invited in accord with ethical standards. Informed consent for their voluntary participation in the research.

Statistical methods

The final exam scores of the experimental group and the control group were compared and analyzed using a *t-test* in SPSS 22.0 software. The measurement data were presented as ($x \pm s$), with $p<0.05$ indicating statistical significance. *Chi-squared test* was employed for the questionnaire survey and the measurement data were expressed as *n* (%). A significance level of $p<0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Comparative analysis of examination results

The final examination results of the experimental group and control group are presented in Table 1. The average score of the experimental group surpasses that of the control group by 12.1 points, exhibiting a highly significant disparity between the two groups ($p<0.01$). These findings indicate that integrating diversified graphical thinking modes into the teaching process is superior to traditional methods, effectively enhancing students' performance in learning inorganic chemistry.

Questionnaire Survey

The questionnaire survey on the overall satisfaction of teaching methods was conducted with a sample size of 55 students in each group. The survey results are shown in Table 2. It was observed that 96.4% of the students in the experimental group acknowledged the integration of diversified graphical thinking modes in the inorganic chemistry course, which was significantly higher compared to the control group following traditional teaching methods ($p<0.05$). Furthermore, based on comprehensive feedback from students, it can be concluded that incorporating diversified graphical thinking modes enhances learning outcomes

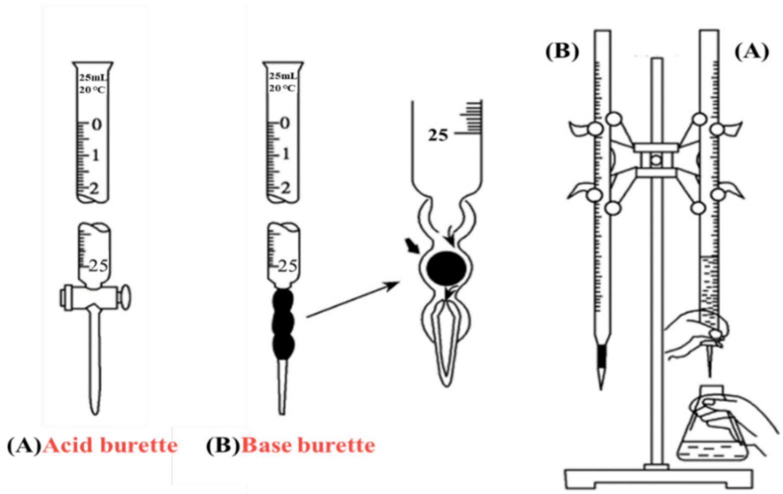

Figure 9: Diagram of acid-base burette and experimental setup.

in inorganic chemistry, as supported by improvements seen in student grades.

To further investigate the acceptance of this course design, an additional questionnaire survey was conducted for the experimental group. From the results presented in Table 3, it is evident that question 1 reflects students' overall satisfaction with the incorporation of diversified graphical thinking modes into the course, with a remarkable 90.9% of respondents acknowledging its beneficial impact on their learning experience. The findings from questions 2-6 indicate that a minimum of 83.6% of students perceive various forms of diagrams as valuable tools for enhancing comprehension across different sections of the curriculum. As seen from the analysis of responses to questions 7-10, no less than 85.5% of participants recognize and accept the integration of diversified thinking mode into teaching practices, leading to heightened interest and enthusiasm towards learning.

CONCLUSION

In summary, the utilization of diversified graphic teaching methods such as mind maps, model diagrams, flow charts, molecular structure diagrams and experimental setup diagrams in conjunction with cases from medicine and real-life can significantly enhance the content delivery in inorganic chemistry education. By utilizing graphical thinking modes, diverse graphical representations are employed to effectively and tangibly illustrate the process and outcomes of cognition, fostering students' enthusiasm for learning, enhancing teaching efficacy and augmenting students' chemistry literacy. Through employing diversified graphical thinking modes for information acquisition followed by comprehensive analysis and problem-solving techniques, students can achieve mastery in a more accurate, logical manner. For educators, this method updates course design while fully engaging learners' motivation to learn without relying solely on passive reading courseware. Furthermore, the teaching method is easily implementable and by integrating the aforementioned instructional design with traditional teaching, a significant enhancement in pedagogical efficacy can be achieved.

Consequently, integrating diversified graphical thinking modes into the practice of inorganic chemistry curriculum truly realizes a "win-win" scenario where both willingness for students to learn and dedication for teachers to teach are effectively implemented. Moreover, this teaching method has been shown to improve exam scores among students while further enhancing the overall educational impact of inorganic chemistry instruction within pharmacy major. The utilization of this pedagogical approach can serve as a valuable reference for the advancement of diverse instructional models in the field of inorganic chemistry.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

SEM: Scanning Electron Microscope.

SUMMARY

Diverse graphical thinking modes were incorporated into the curriculum of inorganic chemistry at higher education institutions and their impact on enhancing learning outcomes in this subject was investigated through comparative analysis and questionnaires. The findings demonstrate that integrating diverse

graphical thinking modes into the teaching of inorganic chemistry can enhance students' engagement and academic performance. This study offers valuable insights for the advancement of diversified pedagogical approaches.

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