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Pedagogical Design through Holistic Education for the Laboratory Instruction in Higher Vocational Education: A Case Study of Acid-Base Titration Instruction in Inorganic and Analytical Chemistry

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ABSTRACT

This study examines the incorporation of holistic educational principles into the teaching of acid-base equilibrium and titration techniques, focusing particularly on a course in inorganic and analytical chemistry. Five holistic educational elements include patriotism, social responsibility, scientific competence, craftsmanship, independent exploration participated in this pedagogical design. Two hundred and twenty-five college students were divided into an experimental group and control. The result shows that the experimental group exposed to holistic teaching practices achieved significantly better results on the final practical exam, with an average improvement of 8.1 points compared to control ($p<0.001$). In addition, over 90% of students in the experimental group reported positive perceptions regarding the integration of holistic educational elements. In the semester teaching evaluation results, the experimental group achieved significantly higher results than control by the independent sample t-test ($p<0.01$). These results provides compelling evidence for the effectiveness of holistic education in improving student learning outcomes, promoting student engagement, and promoting the development of well-rounded individuals in college chemistry curricula.

KEYWORDS

Holistic Education; Acid-Base Titration; Laboratory Instruction; Pedagogical Design; Inorganic and Analytical Chemistry

1 Introduction

Holistic education is a new movement that emerged as a prominent area of study and practice in North America in the mid-1980s [1]. Holistic education includes the intellectual, emotional, physical, social, aesthetic and spiritual aspects of the person and his learning process and emphasizes the balance between them [2-6]. There are still many debates in the academic community about the definition and origin of the connotation of holistic education [3, 7-9]. In addition, due to the influence of traditional Confucianism, Buddhism and Taoism on Chinese education, there is a trend to combine internationalization and localization in holistic education in Mainland China [10]. The main elements of a holistic education include ethics and morals, physical health, cultural values, aesthetics, social responsibility, environmental protection, interpersonal communication, emotional control, willpower and other aspects.

However, there have long been certain deficiencies in the implementation of holistic education in Chinese higher education, especially in higher vocational education [11]. Its shortcomings directly affect the achievement of the goal of medical and health professionals having both moral integrity and professional competence, which cannot fully meet the needs of the new era for talent cultivation in vocational education in China. Therefore, actively researching and deepening the organic connection between holistic educational theory and specialist teaching has become an urgent task for vocational colleges. This is not only a revolutionary point in professional training, but also an important measure to promote highly qualified professional talents [12, 13].

In the medical and health courses at vocational schools, "Inorganic and Analytical Chemistry" is one of the core basic subjects that contain in-depth professional theoretical knowledge and also require very practical experiments [14-16]. What is characteristic of this course of study is the close integration of theory and experimentation, but this dual characteristic also makes it difficult to implement a holistic training, especially in the teaching process of experimental projects. Due to the constraints of traditional teaching environments, holistic education lacks effective entry points into experiential teaching.

Acid-base equilibrium and titration techniques are important parts of experiments in the study of inorganic and analytical chemistry. Its content is abstract in theory, complex in formula derivation and precise in experimental implementation, which increases the challenge of teaching and learning [17]. Based on a holistic education, it is particularly necessary to organically integrate elements such as patriotism, social responsibility, craftsmanship, scientific competence and independent discussion into the teaching design of acid-base balance and the acid-base titration method.

This study takes the experiment "Preparation and calibration of sodium hydroxide standard solution" as an example to examine the implementation path and effect of holistic education in curriculum practice teaching. Five holistic educational elements include patriotism, social responsibility, scientific competence, craftsmanship, independent exploration participated in this teaching. Through the comprehensive design of teaching objectives, course content and teaching methods, the combination of experimental teaching with the concept of holistic education, it is committed to improving the quality of teaching, increasing the learning interest and inner drive of students and the educational goals of all employees to comprehensively achieve the entire process and all aspects and ultimately cultivate high-quality professional talents that meet the needs of the times. This attempt not only corresponds to the national concept of "integration of explicit and implicit education", but also provides practical guidance for the innovation of teaching methods in higher vocational education.

2 Material and methods

2.1 Participants

In the fall semester of 2023, a teaching experiment was carried out to integrate holistic educational elements into the acid-base equilibrium and acid-base titration project. The experiment involves students majoring in pharmacy and medical inspection technology in the class of 2023 at the School of Medicine and Health. They were divided into two groups: the experimental and the control group. The experimental group consists, among others, of the 7th class of Pharmacy 2023 and the 3rd class of the Medical Inspection Technology 2023 with a total of 113 students who received holistic educational teaching. The control group consists of classes 2 and 4 of Pharmacy 2023 with a total of 112 students and received routine instruction.

2.2 Methods of teaching evaluation

The evaluation methods for teaching experiments essentially include final exams for experimental operations, questionnaire surveys and semester teaching evaluations. The preparation and calibration of the sodium hydroxide standard solution was selected in the final experimental test, and the experimental group and control were tested in comprehensive experimental procedures. A questionnaire survey was conducted in the experimental group using online software (www.wjx.cn). Based on 5 core elements of holistic education, five questions with 4 options (strongly agree; agree; uncertain; no) were designed. The semester teaching evaluation is calculated using the following formula.

Evaluation of semester teaching = Usual performance × 30% + Score of the final experimental test × 30% + Score of the final written examination × 40% (1.1)

The usual performance includes attendance, class performance and schoolwork, and the schoolwork is averaged from the grades of all experimental reports. The final written exam is presented in closed book format. All three are evaluated using the hundred-point system.

2.3 Designing teaching objectives based on holistic education

2.3.1 Knowledge objectives

Understand and apply the principle of acid-base equilibrium: Students will be able to explain the concept of acid-base balance and design experimental plans based on this principle, including but not limited to the preparation and calibration of sodium hydroxide standard solution, the selection and preparation of reference substances, as well as the selection and use of indicators.

2.3.2 Skill objectives

Students will be able to competently perform acid-base titrations, accurately determine the end point of the titration, and explain the chemical principles of the changes in solution pH during the titration process. Students are able to operate experimental instruments, including analytical balances, volumetric flasks and separating funnels, in a standardized manner and to precisely carry out processes such as weighing, dissolving and diluting solid substances.

2.3.3 Objectives of whole-person development

After education, students have supposed to promote as follows.

(a) Creating a sense of integrity and responsibility: by emphasizing the authenticity and accuracy of experimental data to promote students' rigorous and pragmatic scientific attitude and sense of integrity, and to guide students to pay attention to the safety and environmental protection of chemical experiments, and to establish a sense of social responsibility.

(b) Improving scientific thinking and experimental design skills: by guiding students to select appropriate experimental methods and steps based on the experimental objectives, to analyze, and discuss the experimental results, and to develop rigorous scientific thinking and experimental design skills.

(c) Cultivating the craftsmanship spirit of continuous improvement: by encouraging students to strive for standardization and accuracy in experimental operations so as to cultivate a diligent, responsible and meticulous craftsmanship spirit.

(d) Developing teamwork and communication skills: by encouraging students to work together in teams during the experimental process, complete experimental tasks together, and present experimental results and analysis conclusions clearly and accurately, so as to improve communication skills and team spirit.

(e) Promoting self-learning and exploration skills: by guiding students to independently learn and explore knowledge related to chemical stoichiometry points, and indicator selection; and by encouraging them to ask questions, analyze and solve problems to cultivate critical thinking and innovative awareness.

(f) Having the ability to lead lifelong learning: by stimulating students' interest in learning chemistry, guiding them to apply their knowledge in practical life, and enhancing their awareness and ability for lifelong learning.

2.4 Holistic educational mapping and integration points

Excavating the elements of holistic education and integrating holistic elements into the teaching process through curriculum design are carried out. More information of five holistic educational elements integrating is shown in Table 1 as follows.

Table 1 Holistic educational integration points in the course of Acid-base titration instruction

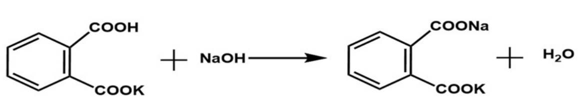
Teaching Content	Holistic Educational Mapping and Integration Points	Teaching Form and Method
Weighing and dissolution of NaOH	The exploits of the outstanding scientist Te-Pang Hou → Patriotism Safety awareness, standardized operation → Craftsmanship	Via video online before class; Class demonstration; Question and answer: Why is sodium hydroxide called caustic soda?
Calculating the stoichiometric point and estimating the end point	The inevitability and universality of terminal error → Strict scientific competence	Class by mouth to ear instruction
Calibrating the concentration of the sodium hydroxide standard solution	The color change in the Erlenmeyer flask→ Independent exploration	Class by mouth to ear instruction; Class by practical training
Processing experimental waste	Treatment of excess NaOH and discolored mixed solution→ Social responsibility for environmental protection	Class by mouth to ear instruction; Class by practical training
Date processing	Calculate and show the calibration concentration → Strict scientific competence	Class by practical training; Discussion

2.5 Implementation strategy for the teaching objectives

Presenting the exploits of the outstanding scientist Te-Pang Hou via video online: to demonstrate Mr. Hou's ambition to save the country through industry, so as to promote patriotism among young students. This film watching activities are checked and supervised on network by each class learning committee member.

An assignment for students to search literature to understand the chemical formula, structure, physicochemical properties, and sources of NaOH, and answer a question: Why is sodium hydroxide called caustic soda? The purpose is to enable students to understand the production process and related chemical properties of sodium hydroxide, to train their self-learning ability, and to maintain a scientific competence by seeking the truth and being pragmatic and knowing its nature and reasons.

The principle of acid-base equilibrium was taught in class. The calibration principle of sodium hydroxide standard solution is the balance of acid-base titration reaction as follows:



The centration of sodium hydroxide standard solution can be calculated:

$$c_{NaOH}=\frac{n_{NaOH}}{V_{NaOH}}=\frac{\frac{m}{M}}{V_{NaOH}}=\frac{m}{V_{NaOH}\times M} \tag{1.2}$$

where c_{NaOH} is the NaOH centration during calibrating (unit: mol/L), n_{NaOH} is the amount of NaOH (unit: mol), v_{NaOH} is the volume of NaOH used (measured in mL), m is the mass of potassium hydrogen phthalate (unit: g) and M is the molar mass of potassium hydrogen phthalate (unit: g/mol), for the calculation 204.22 g/mol.

The steps of the experimental operation were as follows.

(1) Prepare a 0.1 mol/L NaOH standard solution

Weigh 1.0 g of NaOH using a regular balance, dissolve in distilled water in a small 50 mL beaker, transfer to a 250 mL volumetric flask, add distilled water to adjust volume increase and shake well. Demonstrate key points: weighing small amounts of solids, diluting liquids during the weighing and dissolution process, promoting students' scientific competence of meticulousness, patience, and accuracy. Perform leak detection on a volumetric flask, and discuss together, "What other glass instruments need to be checked before use?" This will guide students to think and practice divergent thinking.

(2) Calibrate the concentration of the sodium hydroxide standard solution

Firs, 0.4 g of potassium hydrogen phthalate is accurately weighed using an analytical balance, and three portions are placed into three Erlenmeyer flasks. Dissolve in 25 mL of distilled water and shake well. Then add a drop of phenolphthalein indicator to the potassium hydrogen phthalate solution.

Then, after washing, leak detection and drying the base burette, the prepared sodium hydroxide solution is filled into the base burette and slowly dripped into an Erlenmeyer flask. The color change in the Erlenmeyer flask is observed. When the color of the solution in the Erlenmeyer flask changes from colorless to light red (for 30 seconds without fading), stop the dripping.

The mass of potassium hydrogen phthalate is 0.4 g, so the volume of sodium hydroxide standard solution consumed at the theoretical titration endpoint is 19.59 mL. If the volume of sodium hydroxide standard solution added is about 15 mL, due to weighing error, the addition rate or volume should be slowed down and the color change of the solution in the Erlenmeyer flask should be constantly monitored. Record the volume of sodium hydroxide solution consumed, measure it three times and obtain the consumed volumes V_1, V_2, and V_3 respectively.

Finally, data processing was performed to calibrate the concentration of the NaOH standard solution by calculating the measurement results of three parallel experiments. After the calculation process, the results of calibration concentration are shown as mean ± standard deviation, to promote cultivate students' academic norms and rigorous scientific attitude towards scientific counting.

NaOH solutions and potassium hydrogen phthalate solutions are transparent and colorless. In acid-base titration, the colorimetric indicator phenolphthalein is used to determine the endpoint of the titration. Guiding students to band together during the experimentation process, support each other, and successfully complete the experiment. One team consists of three students from the experimental group and cooperates in titration, reading and recording, observing color changes, processing experimental waste, processing data, reporting experimental results, etc. During the experiment, each member is responsible for one or two tasks, and works together with other members to promote team spirit and solidarity among students.

During class, remind and teach students to record the experimental data, analyze the data after the experiment, display the results with mean ± standard deviation, and one experimental report per person in time after class is submitted as homework.

2.6 Data analysis

From experimental group, 109 samples are effective and four are invalid, while from control, 109 samples are effective and three are invalid. For online questionnaire, 76 volunteers from the experimental group have participated in the survey. All the data were analyzed by software Excel and Origin. The F test was used for homogeneity of variance all the data from both groups. After F test, the independent sample t-test is used to evaluate whether there is a significant difference between both groups or not.

Table 2 Final Experimental Exam Score Distribution: Experimental Group and Control

Groups	Final Exam Score Distribution (%)						
	Mean	S.D.	<60	[60,70)	[70,80)	[80,90)	[90,100]
Control	67.3	8.5	11.82%	41.82%	33.64%	10.91%	1.82%
Experimental group	75.4	11.5	3.67%	21.10%	36.70%	26.61%	11.93%

3 Results

3.1 The score of the final experimental test

The final experimental scores of the experimental group and control are shown and analyzed in Table 2 and Figure 1.

From Table 2, it can be seen that the average value of the experimental group (75.4) is 8.1 points higher than that of control (67.3), which scores are gain by the final experimental test. Particularly, in the score range from 90 to 100, the proportion of the experimental group (11.93%) was significantly higher than that of control (1.82%). The size of the average values of both groups corresponds to the symmetry axis of the normal curve in Figure 1 (experimental group: solid pentagram; control: solid circle). The independent sample t-test was conducted on experimental group and control data (Figure 2), and the probability value obtained was P<0.001 (***), indicating that there is a significant difference in the final exam scores of the experimental group compared to control.

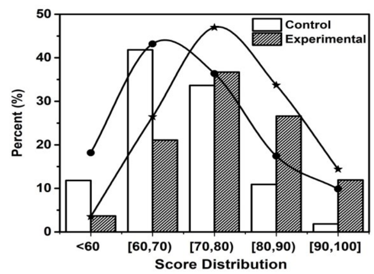


Fig. 1 Distribution of Final Experiment Exam Scores: Experimental Group vs. Control

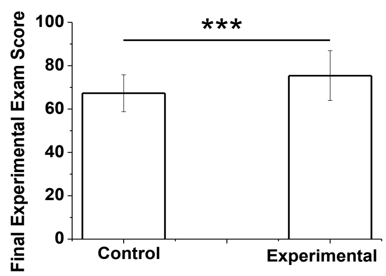


Fig. 2 Independent Samples T-Test Results: Experimental Group vs. Control (***p<0.001)

3.2 The online questionnaire survey

The online questionnaire survey and result analysis are shown in Table 3. It turns out that more than half of the students have a very positive attitude towards the integration of holistic pedagogical elements into experimental teaching, in particular environmental awareness (57.89%) and scientific competence (57.89%). In addition, over 90% of students agree or strongly agree that integrating holistic elements can increase their interest and motivation in learning (90.79%), strengthen their patriotism for industrial development (92.1%), and strengthen their craftsmanship spirit of hard work and specialization (94.74%). More than 90% of students have a positive attitude towards the integration of holistic education elements (strongly agree, agree), which indicates that the integration of holistic education elements increase students' interest in learning and intrinsic motivation. Less than 10% of students chose "uncertain" or "no", which indicates that more details need to be improved in the concrete implementation of holistic education in the teaching process.

Table 3 Online Survey: Results and Analysis

Element	Question	Option			
		strongly agree	agree	uncer-tain	no
Patriotism	Did it promote your patriotism for reforming industry and prospering motherland?	46.05%	46.05%	6.58%	1.32%
Social responsibility	Did it enhance your ecological protection of environmental awareness?	57.89%	34.21%	6.58%	1.32%
Scientific compe-tence	Did it improve your scientific competence of seeking truth and being pragmatic?	57.89%	36.84%	3.95%	1.32%
Craftsmanship	Did it exercise your hardworking and dedicated craftsmanship spirit?	53.95%	40.79%	2.63%	2.63%
Independent exploration	Did it increase your interest and motivation of learning inorganic and analytical chemistry course experiments?	50%	40.79%	5.26%	3.95%

3.3 The semester teaching evaluation

The results of the semester teaching evaluation of both groups were analyzed in Table 4 and Figure 3. From Table 4, it can be seen that the average score of the experimental group (67.8) is 3.2 points higher than that of control (64.6), which results are calculated by the Equation 1.1. Particularly in the score range from 70 to 80, the proportion of the experimental group (33.03%) was significantly higher than that of control (18.35%). The independent sample t-test was performed on the experimental group and control data (Figure 4), and the obtained probability value was 0.0014 (**p<0.01), less than 0.01, indicating that there is a significant difference in the scores of the semester teaching evaluation of the experimental group compared to control.

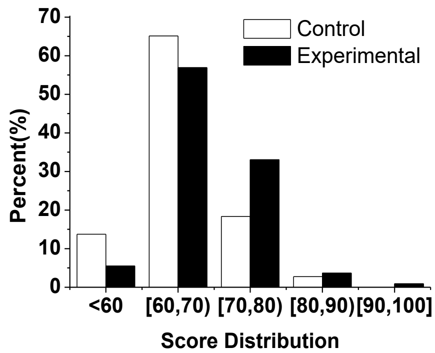


Fig. 3 The Score distribution of semester teaching evaluation: Experimental Group vs. Control

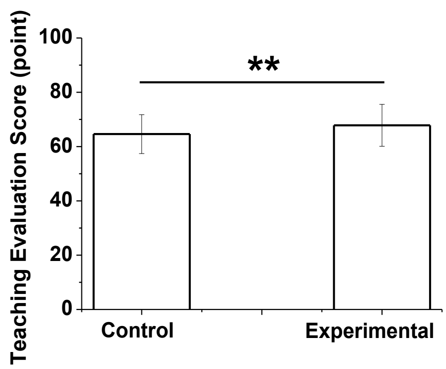


Fig. 4 Independent Samples T-Test Results: Experimental Group vs. Control (**p<0.01)

Table 4 Semester Teaching Evaluation Score Distribution: Experimental Group and Control

Groups	Final Evaluation Score Distribution (%)						
	Mean	S.D.	<60	[60,70)	[70,80)	[80,90)	[90,100]
Control	64.6	7.16	13.76%	65.14%	18.35%	2.75%	0
Experimental group	67.8	7.72	5.50%	56.88%	33.03%	3.67%	0.92%

4 Discussion

4.1 Holistic education plays a positive role in promoting the teaching effectiveness

This study explores the application of holistic education concept in teaching acid-base equilibrium and acid-base titration method, using the example of the experiment "Preparation and calibration of sodium hydroxide standard solution". The integration of holistic educational elements has led a significant improvement in students' experimental final exam scores (see Table 2 and Figure 2). That is to say, the integration of holistic pedagogical elements has had a positive impact on the teaching effectiveness of experimental projects on acid-base equilibrium and acid-base titration.

4.2 Holistic education approaches increase the score of the semester teaching evaluation

The integration of holistic pedagogical elements had a direct impact on the results of the semester teaching evaluation of both groups (see Table 4 and Figure 4). The results show that the integration of holistic pedagogical elements played a positive role in teaching evaluation. The students in the experimental group made significant progress in the final experimental exam.

Their high recognition of the teaching mode clearly shows the positive role of holistic education philosophy in higher chemistry education. However, this study still has certain limitations. For example, the size of the research sample is relatively small and focused on a specific chemical experiment. In the future, the scope of research may be further expanded to include the teaching of other chemical experiments.

4.3 Holistic education is popular with freshmen

Through a series of pedagogical design and implementation, it can be found that incorporating holistic pedagogical elements can effectively improve students' experimental skills, scientific thinking and social responsibility. The five key elements of holistic education were added in the teaching experiment and proved popular with freshmen (see Table 3). The most popular are social responsibility and scientific competence (“strongly agree”). The intellectual and social aspects and their learning process are taken into account in the lessons. In addition, this study mainly focuses on the quantitative assessment of students' learning outcomes. Qualitative research methods can then be combined to examine in depth the effects of holistic educational approaches on students' emotions, attitudes, values and other aspects.

5 Conclusion

Our results show that laboratory instruction combining with holistic education promotes the teaching quality of the inorganic and analytical chemistry course in higher vocational education. Despite its limitations, the results of this study still provide valuable insights for the field of higher education. Next, the concept of holistic education should be further explored and practiced, and deeply integrated into chemistry laboratory teaching, so as to strive to cultivate comprehensive talents with in-depth professional knowledge, excellent practical skills, healthy personality and social responsibility.

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