ORIGINAL ARTICLE

Protocol-Guided Teaching in Secondary Chemistry Education: An Analysis of the Learning Protocol for the Instruction of Omnipresent $CaCO_3$ Based on Student Life Experiences

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Abstract: *Protocol-guided teaching is a student-centered instruction paradigm in which teachers compose learning protocols in advance to guide students through the entire learning process in an effort to foster in them the capacity for autonomous learning. Effective learning protocols can have a substantial impact on classroom outcomes. The purpose of this article is to evaluate the significance of protocol-guided teaching in chemistry education through an examination of a learning protocol designed for the instruction of omnipresent $CaCO_3$. This protocol emphasizes learning based on real-world experience.*

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T*HE Basic Education Course Standards for Chemistry 2022* issued by the Ministry of Education of China emphasize that chemistry education should fully utilize student life experiences and experiment-predominant exploratory activities to achieve heuristic instruction in order to cultivate students' autonomous learning ability (Ministry of Education of China, 2022). The protocol-guided teaching model arose as a significant experiment in teaching paradigm innovation in the context of basic education reform. It adheres to the educational principle of student-centered classroom instruction, shifting from teachers' unilateral knowledge transmission to teacher-student collaboration and from an emphasis on student learning outcomes to an emphasis on the learning process (Wang, 2022). In protocol-guided instruction, teachers construct learning protocols for students in advance based on course standards, textbook content, and student learning conditions. Typically, learning protocols consist of learning objectives, materials, methods, and procedures, and instructors use them to guide students toward more independent learning. Protocol-guided instruction relies on well-designed learning protocols for its effective implementation.

This article analyzes a lesson that junior secondary students learned about "omnipresent $CaCO_3$" using the "Four Steps of Guidance" method of protocol-guided instruction. The learning protocol's four primary parts are student preparation before class, summary and reflection, classroom inquiry, and instructional assessment. The four components work together to build a complete methodology. It can be used as a framework for managing the classroom as well as a learning plan for students. The learning procedure fully incorporates the practice and life experiences of the students.

Before-Class Preparation

The learning protocol includes a variety of pre-class learning activities designed to guide students in observing real-world events related to course content, integrating themselves into learning contexts, and formulating questions for the forthcoming classroom study. Prior to this session, students had a basic understanding of the reaction between calcium carbonate ($CaCO_3$) and dilute hydrochloric acid to produce CO_2, as well as the reaction between clear limewater and CO_2. Students are also familiar with calcium compounds such as limestone, marble, quicklime, and slaked lime. The pre-class learning protocol for the current lecture is as follows:

Comprehending the Learning Objectives of this Lesson

- Discover how to identify $CaCO_3$.

- Learn the use of $CaCO_3$ in manufacturing and living, as well as industrial $CaCO_3$ production methods, and discover how to prepare $CaCO_3$ in the lab and at home.
- Understand the chemical research process, from experiment to phenomenon, conclusion, and application.

(*The purpose of this procedure is to provide students with a foundational understanding of the content and methods of this lesson and to emphasize the most important aspect of this session, namely the identification of* $CaCO_3$*.*)

Pre-Class Learning Tasks

- Task one: Try to answer the following two questions:

To remove a small amount of scale in the kettle at home, you can wash it with:

A. *Vinegar*
B. *Dish soap*
C. *Salt water*
D. *Water after rice rinsing*

The inner wall of the beaker that has held limewater for an extended period of time is coated with a white solid, which has the chemical formula ___________. Remove this layer of white solid using a reagent with a reaction of __________________________ (in a chemical equation).

- Task two: Create a profile for $CaCO_3$.
- Task three: Identify $CaCO_3$-containing substances in everyday life and bring samples to class.
- Task four: Formulate $CaCO_3$-related questions based on knowledge gained from all pre-class learning activities.

(*This procedure is intended to implement the theory of life-based learning in chemistry education. The purpose of the first task's two exercises is to cultivate students' awareness of solving real-world problems with chemical knowledge and to prompt them to review prior* $CaCO_3$*-related knowledge. This lesson's third task is designed to encourage students to seek out more extensive information about* $CaCO_3$ *using digital media and to increase their interest in learning. The purpose of Task 4 is to allow students to recognize chemical components in everyday substances and to make them aware of the pervasiveness of chemistry in our lives. On the basis of these pre-class learning activities and relevant textbook section readings, students pose queries* *that they wish to gain a deeper understanding of in subsequent learning processes.*)

Classroom Inquiry

Activity-based learning can increase student engagement in the classroom and help them develop their analytical and problem-solving abilities. Plans that are well structured can help teachers accomplish the learning objectives and considerably increase the efficacy of inquiry-based learning in the classroom. This lesson's learning protocol for the class inquiry follows the formula "question + activity."

i. Question One: How do I identify $CaCO_3$?

Activity: Using laboratory equipment, determine whether the specimens collected at home contain $CaCO_3$ and document the experimental procedures using **Table 1**.

Table 1. Lab Experiments on Specimens Collected at Home.

Specimens	Experiment Design	Experimental Phenomena	Experiment Conclusions

(*Based on the general path of scientific inquiry: question—hypothesis—research design—experimentation or literature review—conclusion, students are required to engage in group discussion to develop an experiment design using instruments and chemicals available in the lab and to conduct the experiments in groups to determine whether their home specimens contain $CaCO_3$. Among students, there are generally two prominent experimental methods: (i) Burn the solid specimen over an alcohol flame, place it in a test tube with water, and then add phenolphthalein drop by drop to observe the liquid turn red; (ii) Place the specimen in a test tube and add diluted hydrochloric acid drop by drop to produce bubbles; the gas produced is then introduced into clear limewater to make it turbid. Students tend to believe that either of the two phenomena can determine the presence of $CaCO_3$ in their specimens. The teacher then instructs the students to conduct one more experiment, which involves dripping diluted hydrochloric acid into a test container containing a chemical whose name is concealed and comparing the experimental phenomenon to that of the second of the preceding methods. The same phenomenon is observed, and students have discovered that the compounds used in the experiment are carbonates other than calcium car-*

bonate. Students recognize at this point that their experimental methods are insufficient, as they can only determine that the tested substance is carbonate. To establish that it is $CaCO_3$, they must demonstrate that it contains the element calcium. To stimulate students' interest in further chemistry study, the teacher can demonstrate how to identify calcium in a compound through a flame reaction, which will be taught at the senior secondary level.)

ii. *Question Two: What Is the Use of $CaCO_3$?*

Activity: Students present the information on the applications of $CaCO_3$ that they gathered prior to class.

(*The purpose of this activity is to reinforce students' comprehension of the chemical concept that a substance's use is determined by its properties*.)

iii. *Question Three: How to Make $CaCO_3$ with High Purity on an Industrial Scale*

Activity one: Watch a video about survival in the wild that incorporates the process of using shells to produce $CaCO_3$ of high purity.

(*After watching this video, students evaluate the procedure's logic and understand how $CaCO_3$, CaO, and $Ca(OH)_2$ are converted, preparing them for the discussion that follows on the large-scale manufacture of high-purity $CaCO_3$. Students learn through this practice that chemistry knowledge can be applied to save lives on occasion*.)

Activity two: Students have conversations in groups about how to make high-purity $CaCO_3$. Each group develops an experimental design that will be assessed by other groups based on their understanding of the characteristics of $CaCO_3$ and its presence in the environment. The uniform experiment method will be chosen based on the most logical strategy.

(*This activity is intended to enhance students' ability to design experiment methods and evaluate the applicability of knowledge*.)

Activity three: Students prepare $CaCO_3$ in the laboratory using carbide slag as a source material to simulate the industrial production of $CaCO_3$.

(*This experiment gives students the opportunity to comprehend how industrial production may transform waste into useful materials and to cultivate awareness of the prudent use of resources*.)

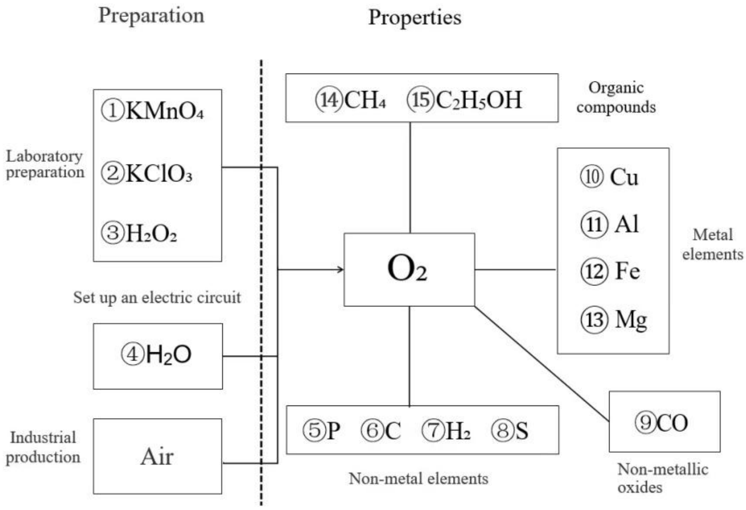


Figure 1. A Basic Knowledge Structure of O_2.

Summary and Reflection

The purpose of the summary and reflection procedure is to encourage students to derive research methods from classroom inquiry activities. This step's learning protocol stipulates that students must be able to:

- Establish a framework for the conversion between calcium compounds such as $CaCO_3$, CaO, and $Ca(OH)_2$.
- Generalize the three major components of substance research: property, use, and method of production.
- Construct knowledge structures for common chemicals (using the O_2 knowledge structure diagram as an example, as illustrated in **Figure 1**):

Instructional Assessment

The Basic Education Course Standards for Chemistry 2022 place a strong emphasis on the value of a thorough evaluation process that includes evaluations of students' understanding of chemistry, scientific reasoning, scientific practice, and scientific attitudes. By combining teaching, learning, and evaluation, classroom education needs to change from a focus on knowledge delivery to one on the development of critical competencies (Ministry of Education of China, 2022). In protocol-guided instruction, evaluations of pre-class independent student learning, problem-solving, mastery of learning skills and processes, and consolidation of knowledge in and after class are all woven into the instructional assessment process. The protocol-based evaluation is a summative assessment in that it helps to consolidate learning contents and processes. It is a formative assessment since it is integrated into every stage of student learning and guides students through the entire inquiry process. The exercises that follow are part of this lesson's instructional assessment.

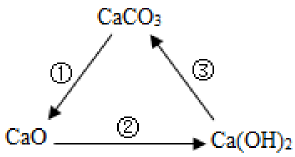
i. In-Class Assessment

Exercise one:

The main component of limestone is $CaCO_3$. Which of the following statements is false? ( )

- *A. $CaCO_3$ is a carbonate.*
- *B. Shells and pearls contain $CaCO_3$.*
- *C. $CaCO_3$ is easily soluble in water.*
- *D. $CaCO_3$ can serve as a calcium supplement.*

Exercise two:



For this triangular diagram of Ca, which of the following statements is false? ( )

- *A. Reaction (1) can be applied to producing quicklime.*
- *B. Reaction (2) can release heat.*
- *C. CaO can serve as a desiccant for certain foods.*
- *D. Reaction (3) must involve CO_2.*

ii. After-Class Assessment

Prepare $CaCO_3$ at home, observe and describe experimental phenomena, and record the process on video.

(*This after-class experiment question is meant to motivate students to put what they have learned in the classroom into practice. An interesting and motivating at-home experiment can help students develop their scientific skills and increase their enthusiasm for learning chemistry while also testing their understanding of the material covered in the course*.)

Reflections from the Teacher

The development of this lesson's learning protocol is an application of the student-centered and teacher-led instruction concept, a basic premise underlying the protocol-guided teaching paradigm. The learning protocol, which closely connects classroom instruction with student life experiences, assists students in achieving learning objectives by leading them through the phases of pre-class preparation, classroom inquiry, summary and reflection, and instructional evaluation. It allows students to participate in a session of experiential, cooperative, and enjoyable classroom learning.

It is essential to highlight the results of the most remarkable activities. According to the learning protocol, students must gather information about the applications of $CaCO_3$ prior to class and present it in class. This not only motivates students to learn independently but also makes them aware that online resources are an essential source of information for chemistry study. If the instructor gave an explicit lecture on the applications of $CaCO_3$, it would be tedious and repetitive. In order to identify $CaCO_3$ in specimens collected at home, students are instructed to design experiments, comment on each other's designs, select the best plan and most reasonable experimental setup, and conduct the experiments in groups based on their prior knowledge of the properties and applications of $CaCO_3$. Through experimentation, they discern the proper method for identifying $CaCO_3$ and even generalize about the methods commonly used to identify members of the carbonate family. The program "Survival in the Wild" functions as an ideal introduction to the preparation of $CaCO_3$ and introduces students to the methods of $CaCO_3$ preparation in the laboratory. Using carbide slag as a basic material to simulate the industrial production of $CaCO_3$ is a valuable lesson in sustainable development for humans. This activity teaches students that chemistry is derived from life, thereby contributing to the advancement of human society (Zou, 2022). This protocol for learning has some limitations. Due to time constraints, the procedure for identifying $CaCO_3$, for instance, only allows students to experiment with a limited number of chemicals. This restriction is inappropriate; students should be permitted to conduct more extensive experiments to determine the optimal identification technique.

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