# Educational Game Design for Chemistry Disciplinary Core Competencies

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**Abstract.** Disciplinary core competencies is the solution for the implementation of core competencies and the key to fulfilling the fundamental task of moral education and talent cultivation. As a complex system of the integration of information technology and education, educational games should meet the needs of students' disciplinary core competencies development. Taking chemistry as an example, this paper starts from disciplinary core competencies and discusses the design of educational games for disciplinary core competencies from two aspects: educational game design, educational game application.

**Keywords:** Disciplinary Core Competencies; Educational Game; Educational Game Application.

## 1. Introduction

In order to meet the challenges of technological progress, economic and social development, and globalization, countries have proposed the concept of core competencies based on their own environments and judgments of future challenges. Core competencies focuses on cultivating future citizens and enabling students to solve complex problems in unknown environments. It is the essential competencies required for individuals to lead the lives they want and for the smooth operation of society. A comprehensive analysis of the "21st Century Skills" in the United States, the "21st Century Competencies" in Japan, the "Core Competencies " of UNESCO, and the "Key Competencies" of the European Union reveals that core competencies consists of three levels: disciplinary core competencies, cross-disciplinary common competencies, and self-development competencies. Among them, disciplinary core competencies is a core competencies cultivation plan based on the current teaching situation in schools and an effective solution to the problem of core competencies concepts being superficial in educational reality. [1]

Educational games are video games designed to promote student learning. Existing research shows that educational games can stimulate learning motivation, change students' learning paths, and improve learning outcomes [2]. However, most educational games are designed to promote the cultivation of a single skill or to acquire subject knowledge, lacking educational games that aim to cultivate students' disciplinary core competencies. This study will take cognitive apprenticeship as the theoretical basis, use the topic of energy changes in chemistry as the content, and design an educational game for chemistry disciplinary core competencies. The game will be applied in high school chemistry classrooms to verify its effect on promoting students' chemistry disciplinary core competencies.

## 2. Theoretical Basis

### 2.1 Chemistry Disciplinary Core Competencies

Chemistry disciplinary core competencies is a component of scientific competencies, including chemistry competencies, chemistry information competencies, chemistry ability, cooperative ability and language competencies, chemistry thinking competencies, cross-disciplinary cooperative comprehensive competencies, as well as emotions, attitudes, and values. The cultivation of chemistry disciplinary core competencies requires creating real situations for students, providing a humanistic

environment based on chemical formulas in teaching, and using experiments to enhance students' experimental skills to deepen their understanding of chemical reactions. Therefore, China has proposed the "General Senior High School Chemistry Curriculum Standards" to guide the curriculum design of school teaching. The curriculum standards divide chemistry disciplinary core competencies into five dimensions: "Macroscopic Identification and Microscopic Analysis", "Change Concepts and Equilibrium Thinking", "Evidence Reasoning and Model Cognition", "Scientific Inquiry and Innovative Awareness", and "Scientific Attitude and Social Responsibility". [3]

The high school chemistry curriculum design based on the curriculum standards adopts a large-unit teaching model, divided into multiple themes. Each theme involves multiple dimensions of disciplinary core competencies, creating a learning environment based on real situations for students, connecting chemistry with life, and using experiments to cultivate students' skills and attitudes.

This game is closely related to school teaching, using existing course content as the basis for game content, synchronizing the goals of school teaching and the game, thereby ensuring the effectiveness of educational games in cultivating core competencies and maintaining a balance between the entertainment and seriousness of the game.

### 2.2 Cognitive Apprenticeship

Cognitive apprenticeship focuses on the teaching process, paying attention to both expert behavior in problem-solving and situational learning. Compared with traditional apprenticeship, cognitive apprenticeship externalizes students' cognitive processes, emphasizes the contextuality of knowledge, and pays more attention to the application of knowledge in different situations. Cognitive apprenticeship is one of the teaching models of situated cognition theory. It divides the learning environment into four dimensions: content, method, sequence, and sociology, which jointly guide the construction of the learning situation. Content refers to the type of knowledge required for expert skills, method refers to the methods that promote the development of expert skills, sequence is the order of learning activities, and sociology refers to the social characteristics of the learning environment. In cognitive apprenticeship, students complete the role transformation from novice to expert through legitimate peripheral participation. Students' learning activities include observation, imitation, practice, and innovation activities. In a learning environment based on real situations, students comprehensively apply multiple strategies and skills to complete learning tasks with the support of carefully designed scaffolding. [4]

This game is based on the theory of cognitive apprenticeship, designs game prompts in line with the scaffolding principle, and provides timely feedback to students to promote their reflection. The difficulty of the game levels is designed in an ascending order according to the students' learning sequence, and multiple situational problems are arranged to help students transform their experience into knowledge through practice.

## 3. Game Design

According to the division of core chemical competencies in the high school chemistry curriculum standards, the content related to energy changes in Chinese high school chemistry is integrated in a large unit teaching approach. The teaching objective of this unit is to enable students to know common endothermic and exothermic reactions, and establish the concept that energy changes accompany material changes; students can understand the reasons for energy changes from the perspectives of the energy possessed by reactants and products and the breaking and formation of chemical bonds; students can qualitatively and quantitatively study the heat changes in chemical reactions. The content involves multiple aspects of core chemical competencies, including macroscopic and microscopic, change and equilibrium, evidence reasoning, and innovation ability. In the teaching of the energy change topic, students should solve problems related to life in a situational teaching environment and complete learning activities under the guidance of teachers.

Educational games construct imaginative scenarios based on set rules for students. In the low-pressure environment created by the game world, students can repeatedly test the boundaries of game rules using various strategies. The game levels are generally arranged in an ascending order of difficulty, encouraging students to achieve learning goals through exploration, trial and error, reflection, and correction. This is in line with the teaching philosophy of cognitive apprenticeship [6]. Therefore, this study designs an educational game for core chemical competencies based on cognitive apprenticeship.

The components of a game include game rules, game characters, game scenes, game interaction, and game feedback. Among them, game rules are the core, which stipulate what game characters can and cannot do and how to do it. Game characters are the virtual avatars of players in the game, and different characters give players different experiences. Game scenes are the specific environments where players are in the game, carrying information about the construction of the situation and the world. Game interaction is the interaction between players and game characters, which determines the players' game experience. Game feedback is the feedback information that players obtain about their own behavior during the game, reflecting their performance in the game.

Educational games are based on games and integrate teaching goals with game goals. Under the premise of goal consistency, they balance the entertainment of the game and the seriousness of teaching. The author combines the energy changes of chemical reactions with the acceleration and deceleration of cars and designs an educational game for core chemical competencies called "Energy Change Taxi". Students play the role of taxi drivers and choose appropriate fuels for the taxi. Exothermic reactions provide power for acceleration, and endothermic reactions provide power for deceleration. Before each level starts, there are clear prompts informing students of the tasks to be completed in the level and the types of fuels required to complete the tasks. At the end of each level or when a student fails to pass a level, the game provides feedback to the student. The feedback information includes a visual chart comparing the energy changes of the selected and unselected chemical equations, the gold coins the student has earned during the level, and the time spent on the level.

The game is equipped with prompts that support both learning and playing. According to the cognitive load theory, cognitive load is divided into intrinsic cognitive load and extrinsic cognitive load. To better promote learning, the intrinsic cognitive load of the learning content should be optimized, and the extrinsic cognitive load that affects learning should be reduced. The cognitive load in the game includes the cognitive load related to game interaction and the cognitive load related to learning. In this game, the prompts for game interaction are regarded as extrinsic cognitive load, and the prompts for learning content are regarded as intrinsic cognitive load. The prompts in the game act as scaffolds to support students' exploration, guiding them to achieve both the game and learning goals. The scaffolds are distributed in the introduction before each level and the prompts during the level, helping students reflect and adjust their game strategies to solve problems within the rules.

The level design of the game follows the basic principles of cognitive apprenticeship, that is, game interaction progresses from simple to complex, game difficulty increases from easy to difficult, and the game environment evolves from single to comprehensive. The game is divided into five levels. Level one requires students to select one of the listed exothermic reaction equations as the acceleration power for the taxi; level two requires students to select one of the listed endothermic reaction equations as the deceleration power for the taxi; level three requires students to balance a listed combustion equation of a hydrocarbon; level four requires students to select one of the listed exothermic reaction equations as the acceleration of the taxi, where each equation is designed based on different amounts of substances, requiring students to perform basic numerical calculations and comparisons; level five is a free level where students can use the gold coins accumulated from the previous levels to purchase substances in the store and design their own equations to complete the combination of acceleration and deceleration powers.

The game interaction design progresses from simple to complex. In level one and level two, students are required to click on the selected chemical reaction equation; in level three, students are

required to input the calculated numbers; in level four, students are required to perform partial calculations before selecting the appropriate equation; in level five, students are required to comprehensively use multiple interaction methods such as selection and input.

## 4. Application and Discussion

On November 30, 2024, the author conducted an application research of the "Energy Change Taxi" educational game with 62 students from two classes of the second grade in YY High School, XX City. Class A was informed of the specific usage method of the game and the expected learning goals before using the game, while Class B was not informed of the specific usage method of the game, in order to determine whether the game achieved the expected effect.

The student questionnaires were collected on the night of using the game, and a total of 59 questionnaires were collected, of which 57 were valid. The collected data were standardized using SPSS software, and then the reliability and validity of the questionnaire were analyzed. The Cronbach's α coefficient for reliability reached 0.954, and the KMO for validity reached 0.875, both of which were relatively ideal.

After analysis, it was found that there was no significant difference in the experience of game difficulty between Class A and Class B, indicating that the game interaction design was reasonable and the level difficulty design met the students' acceptance of video games.

58.66% of the students reached level four, and 39.66% reached level five, indicating that students were able to use the game as expected. Further research on students' behavior in the game reveals that 55.17% of the students repeated playing level one more than twice, while in level five, this behavior accounted for only 39.66%, indicating a negative correlation between the complexity of game interaction and students' exploratory behavior. On December 2, 2024, the author randomly selected four students from the school for interviews. The interview results confirmed that students have a relatively high acceptance of the complexity of game interaction, but overly complex interaction can reduce their interest in persistent exploration. At the same time, students believe that the prompts before each game level are very important, especially the design of separately introducing game rules and learning content, which can better enhance students' understanding of both the game and teaching objectives.

During the interviews, students demonstrated core competencies in chemistry, such as micro and macro perspectives, change and balance, and evidence-based reasoning, indicating that this game is targeted at developing students' core competencies in chemistry. However, it performed poorly in terms of innovation, possibly due to the complex interaction design in level five, which did not receive an ideal response from students.

## 5. Summary

The research shows that the consistency between teaching objectives and game objectives can ensure the balance between the entertainment and seriousness of educational games. Educational games designed based on cognitive apprenticeship can cultivate students' core competencies in chemistry under the guarantee of objective consistency. The interaction design of the game has a significant impact on students' game motivation.

Core competencies in a subject are the implementation plans of core competencies based on specific subjects. This game is only designed for core competencies in chemistry. Although research has proven that educational games can cultivate core competencies in chemistry, they still need to be based on the existing school teaching system. In the future, it can be expanded beyond the school teaching system to explore the promoting effect of educational games independent of the curriculum on core competencies in a subject.

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