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A Century Construction of Chemistry Learning Abilities in Chinese Middle Schools: A Text Analysis Based on 28 Curriculum Standards

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ABSTRACT

Chemistry learning ability is an important learning outcome that students will get through learning chemistry. National Curriculum Standard is a guidance document that defines the nature, objectives and the content of the curriculum, as well as the implementation recommendations. After sorting out the contents of Chinese Chemistry Curriculum Standard (CCCS), based on the framework of the latest PISA (Program for International Student Assessment) and Gagne's theory of classifying learning results, the target chemistry learning abilities in the chemistry curriculum standard were divided into five disciplinary abilities, which are the basic ability, comprehensive ability, problem solving ability, epistemology, and creative thinking. The one-hundred year development of CCCS has gone through the stage of balanced development of chemistry learning abilities from the basic ability and epistemology as the main body to the problem-solving ability as the core, with epistemology as the support. In the chemistry curriculum standard, the curriculum goal is not consistent with the learning abilities required by the teaching implementation requirements, which are reflected in two aspects: first, in the evolution process of nearly a hundred years, most of the epistemology ability requirements such as personality quality, emotional attitude and values are not reflected in the documentary of teaching implementation; second, in 1948-2000, the required practical application ability is not reflected in the specific teaching. Finally, This study provides ideas for the study of curriculum standards from the perspective of learning ability, and puts forward relevant suggestions for the goal writing and implementation of Chinese middle school chemistry.

1. Introduction

Chemistry is an important part of science education. In China, chemistry is a basic course for middle school students, who used to begin to learn chemistry in grade 9. In 2018, the Third Plenary Session of the 18th Central Committee of the Communist Party of China deliberated and passed the decision of the CPC Central Committee on several major issues of comprehensively deepening reform, which carried out a major reform of the college entrance examination, stipulating that students study chemistry uniformly in Grade 10. After entering grade 11, they have the right to choose whether to continue to study this subject or not. In China, whether students study chemistry in the senior years of middle school or not directly determines the scope of their university major choice. The development of China's secondary education system, which focuses on subject-specific teaching, has formed the growth path of all students. The structure and content of chemistry curriculum are also changing with the different requirements of China for talented people (Voogt & Roblin, 2012). In 2018, referring to the core competence framework of OECD (Ananiadou & Claro, 2009) and EU (European Union, 2008), the Ministry of education of China promulgated Chinese High School Chemistry Curriculum Standard with the core competence of chemistry as the main curriculum goal. The core abilities of chemistry in CCCS includes five aspects: “macro identification and micro analysis”, “change concept and balance thought”, “evidence reasoning and model cognition”, “scientific exploration and innovation consciousness”, “scientific attitude and social responsibility” (Ministry of Education, 2018).

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2. Rationale

This study refers to scholars' research on learning results and abilities to set up the theoretical framework, including Gagne's theory of classification of learning results, scientific literacy assessment framework of PISA and Chinese scholar Lei Wang's classification of chemistry learning abilities. Gagne believed that learning outcomes are educational goals. He divided learning outcomes into five categories: verbal information, intelligence skills, cognitive strategies, motor skills and attitudes. Speech information includes name, symbol, fact and principle. Intelligence skill is the ability that learners acquire to use symbols to do things outside, such as using symbols, making decisions, using rules or knowing how to do things. Intelligent skills can be divided into four interrelated categories, from low-level to high-level, which are discrimination, concept, rule and high-level rule. Cognitive strategy is a kind of special intelligent skill, which is the ability of people to use concepts and rules to adjust and control the internal, including the regulation of attention, learning, memory and thinking. Motor skill is the ability that individuals acquire to control muscle coordination with a set of operation rules. Attitude is a relatively stable internal state that affects the direction of individual behavior choice(Gagne, 1985).

The categories in Scientific Literacy framework of PISA 2015 include: contexts, scientific knowledge, contexts, and cognitive demand. There are three parts required for scientific literacy, which include explaining phenomena scientifically, evaluating and designing scientific inquiry, interpreting data and evidence scientifically. Types of scientific knowledge include content knowledge, procedural knowledge and epistemic knowledge. Contexts include health, natural resources, the environment, hazards, and the frontiers of science and technology in personal, local/national, and global settings. Cognitive demand includes: (1) carry out a one-step procedure, for example, recall of a fact, term, principle or concept or locate a single point of information from a graph or table; (2) use and apply conceptual knowledge to describe or explain phenomena, select appropriate procedures involving two or more steps, display data, interpret or use simple data sets or graphs; (3) analyse complex information or data, synthesize or evaluate evidence, justify, reason given various sources, develop a plan or sequence of steps to approach a problem(OECD, 2019).

Wang Lei, the leading researcher of Chinese chemistry curriculum and teaching theory, divided the chemistry learning ability into core knowledge, core activity experience, subject cognitive mode, learning ability activity and performance. The core knowledge of chemistry includes inorganic matter, organic matter, chemical reaction, chemistry and life. The core activity experience of chemistry includes the examination of material property, the inquiry of reaction law, the inquiry of material composition, the examination of material, the separation of material and the preparation of material. The ways of cognition of chemistry include the angles, ideas and categories of cognition. The activities and performance of chemistry competence include transfer innovation, application practice and learning understanding(Wang , 2018).

To set up the theoretical framework of Chinese chemistry learning ability based on the above research, this paper has done the following work. First, according to Gagne's theory, this paper regards the ability of chemistry as the result of learning chemistry. Curriculum standard is a teaching guidance document which stipulates the nature, objective, content and implementation of the subject curriculum. Therefore, it can be reflected through the curriculum objectives, teaching implementation and other parts of the chemistry curriculum. Second, Gagne's classification method can provide a reference for the first level indicators of the subject classification framework in this study. For example, speech information and movement skills can basically correspond to the basic abilities and comprehensive abilities in the classification of this paper. Furthermore, problem solving ability is a collection of intelligent skills and cognitive strategies. Third, the contexts and cognitive demands in the scientific literacy framework of PISA 2015 can provide reference for the abilities of thinking parts in the framework of problem solving and epistemology, and PISA 2018 proposed the assessment of creative thinking. Fourthly, on the basis of complying with the educational psychology theory and the knowledge system of chemical education with Chinese characteristics, this study also refers to the framework of chemistry learning ability of Chinese scholar Wang Lei, and divide the problem-solving ability into the following aspects: practical application, experiment operation, cooperative communication, scientific method, and cognitive thinking. Fifthly, the innovation of this study is that it not only pays attention to the changes of students' chemical thinking and learning behavior, but also adds epistemology. This is less mentioned by previous scholars in the research of chemistry learning ability. Epistemology is also one of the important abilities to be cultivated in science education, which includes the nature of science (chemistry), values, emotional attitude, and personality quality. For example, Lederman, Ng (Norman g.) and Erduran, sibel studied the relationship between natures of science and scientific inquiry, and found the importance of teachers and students' understanding of nature of science for science curriculum and teaching practice(Lederman, 2019)(Erduran & Guilfoyle & Park & Chan & Fancour, 2019). Epistemology is also a kind of ability classification that inclines to emotion. American psychologists such as Peter Salovey and Daniel Goleman defined the concept of emotional intelligence(Zins & Elias, 2006). The organization of Collaborative for Academic, Social, and Emotional Learning believes that social emotion is the application of emotional intelligence in various situations. It is the ability that can be obtained by learning, practicing and applying in specific situations just like the development of intelligence(CASEL, 2003). At present, all countries in the world are committed to developing students' emotional ability through curriculum reform. Therefore, in the study of chemistry learning, in addition to the results of intellectual factors, students should also develop the ability of emotional intelligence, which focuses on the epistemology of values, emotional attitude, personality quality and nature of chemistry. At last, this paper divided chemistry learning abilities into basic abilities, comprehensive abilities, problem-solving, epistemology and creative thinking (see in Table1).

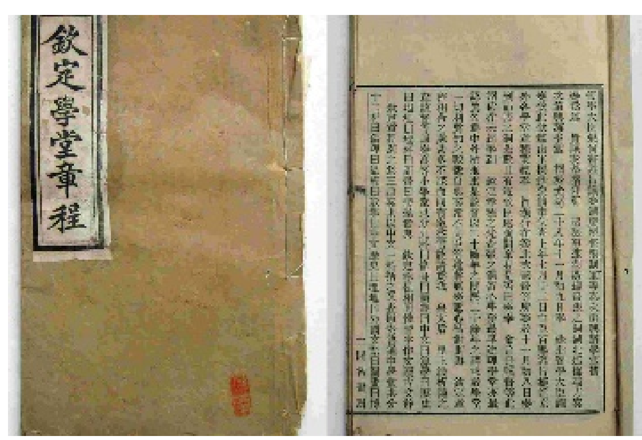

Figure 1. The first document to stipulate the system of schooling issued by the state in modern China

3. Method

In this study, 34 versions of Chinese Chemistry Curriculum

Standards (CCCS) from 1902 to 2019 (see in Table 2) are collected, the target text of the curriculum and the teaching text of redox reaction are analyzed by the qualitative text analysis method. Most of the texts of the curriculum goals in CCCS are very concise, and there are few enumerable expressions, so the coding method of counting can be adopted. In different versions of Chinese chemistry curriculum standards, the text of curriculum goals are different. Especially in the 21st century, the length of CCCS increased dramatically. It is not clear to calculate the frequency of each ability in each year, so weight is also used. In this study, 28 texts of curriculum objectives of curriculum standards were collected. Among them, there was no clear curriculum goal requirement in 1902 and 1904, and it was not until 1923 that there was requirement; the curriculum goals of the CCCS of junior and senior high schools were the same in the year of 1936 and 1941. Therefore, the coding of 1941 is used the middle school version. There was no target requirement in 1950, so there is no coding statistics of the above versions in table 2. The curriculum goals in the 28 versions of CCCS were coded according to the above chemistry learning abilities. Researcher A encoded 256 items and researcher B encoded 259 items. In order to ensure the reliability of coding, test was conducted after codes formed. The results were compared item by item, and 241 items were the same. The consistency of classification was 93.59%. After consistency, the difference items were checked one by one, discussed and modified the content of ability expression, and finally had 254 items of consistent code. If it is only focused on the target text of the Chinese chemistry curriculum standard, the changing situation of the learning ability in the past 100 years can not be clearly analyzed, which is also one-sided to simply reflect the change of the learning ability of chemistry by frequency. Therefore, this study adds the text analysis of teaching implementation parts of curriculum standards. Because the text of this part is long and the description of chemistry learning ability is detailed, the way of discourse analysis is also adopted with the matching degree of chemistry learning abilities required in the curriculum goals to summarize the evolution process in the past century. The teaching theme of redox reaction is selected to analyze because it is a common case in chemistry teaching in middle school, and it appears more frequently in the curriculum standard. The change rule of chemistry learning ability in the past 100 years by text analysis of the teaching implementation to redox reaction is also summarized.

4. Results

The Embodiment of Chemistry Learning Ability in Curriculum Goals: From Single Focus to Balanced Development.

Before the founding of the people's Republic of China, the standard of chemistry curriculum was described in classical Chinese, and the length was relatively short. After entering the 21st century, the length of curriculum objective increased, the types of abilities mentioned increased gradually, and the total frequency and weight of abilities changed regularly. The total frequency was 7-13 in 1929-1952, about 5 in 1954-1990, and 11-27 in 1992-2017 (see in Figure 2). Based on the analysis of the curriculum goals requirements for each dimension of the learning ability, it can be seen that the basic ability, epistemology and problem-solving are always reinforced, while the comprehensive ability and creative thinking are seldom concentrated (see in Figure 3). The proportion of epistemology ability in chemistry curriculum standard is always over 20%, placed first in most of the time. The basic ability is more than 8%, showing a state of one after another, and the problem-solving ability is gradually strengthened as a whole. Comprehensive ability and creative thinking are sometimes absent in the early stage, and have experienced a process from ups and downs to stability. Among them, the comprehensive ability is more complex and comprehensive than basic ability, which belongs to the process ability and is difficult to be reflected in the curriculum goals at the macro level. On the whole, in the past 100 years, CCCS has gone through a stage of development. Previously, it focused on basic abilities and epistemology separately, with a single ability as its focus. Now it focuses on problem-solving ability, with epistemology as its support, which reflects the balanced development of chemistry learning abilities.

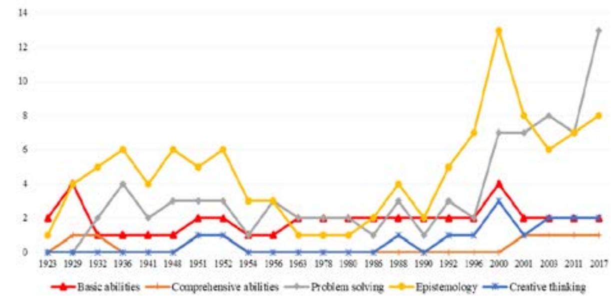

Figure 2. Frequency table of chemistry learning ability in CCCS Goals in the past 100 years

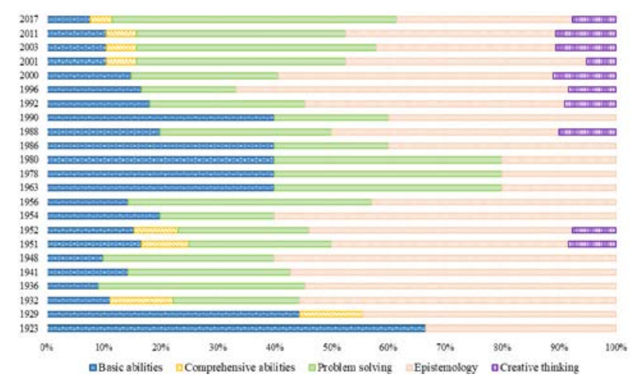

Figure 3. A century evolution of chemistry learning ability in the CCCS Goals

In the past century, problem-solving ability has been on the rise and diversified. Problem solving ability includes five dimensions: experimental operation, cooperative communication, scientific method, practical application and cognitive thinking. Only 1923 and 1929 versions of the CCCS have no clear requirements on problem-solving ability, and in the early stage, CCCs mainly focuses on cognitive thinking and practical application. In the middle stage, CCCs only focuses on practical application. In the later stage, it forms a balanced development of problem-solving ability guided by scientific exploration (see in Figure 4).

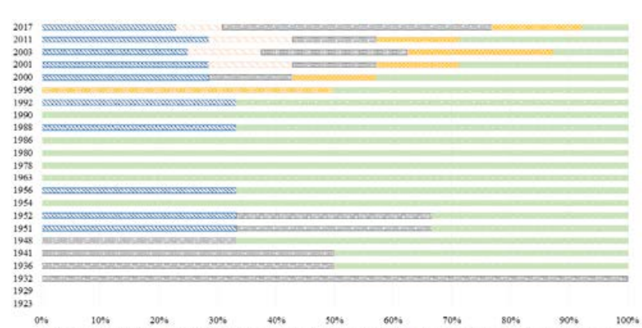

Figure 4. A century evolution of secondary ability requirements of chemistry problem solving in CCCS Goals

Epistemology includes four sub-dimensions: emotional attitude, personality quality, nature of chemistry and values. The overall presentation is from attaching importance to the external knowledge of students and disciplines to attaching importance to the internal experience and Nature of science. The harmonious development tends to be diversified and balanced (see in Figure 5). The development of epistemology ability can be divided into three stages: in the first stage, before the founding of the people's Republic of China, CCCs attached great importance to the nature of chemistry, students' emotional attitude and personality quality. It focused on helping students to understand the nature of chemistry and the relationship with life, cultivating their interest in learning and forming the habit of good observation, and having such virtues as diligence and honesty. The second stage is from the founding of the people's Republic of China to the end of the 20th century. It focused on the education of "dialectical materialism" and "patriotism", so as to shape students' values. The third stage is in the 21st century, forming a pluralistic period of balance between chemistry and students' internal nature. The nature of the discipline began to emphasize the relationship between chemistry and other disciplines, natural environment, human life and social development, etc, with close relationships to the sustainable development of the environment.

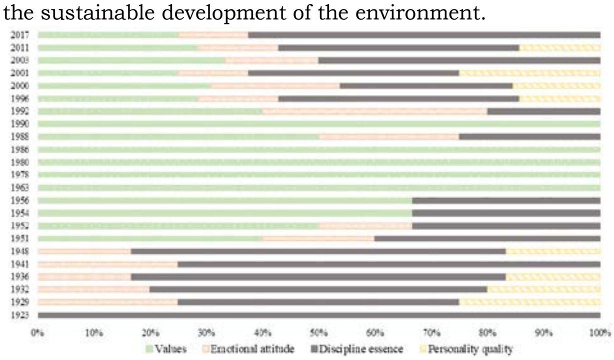

Figure 5. A century evolution of chemistry epistemology secondary ability requirements in CCCS Goals

The Consistency in Chemistry Learning Abilities between Curriculum Goals and Teaching Implementation: Taking Redox Reaction as an Example

In 1948, redox reaction was formally defined in the chemistry field: before and after chemical reaction, a kind of reaction with the change of oxidation number of elements is called redox reaction (Calvert, 2006). Because the term oxidation-reduction reaction appeared later than the Chinese modern chemistry curriculum standard, there was no clear teaching content in the version before 1948. But in the 1923-1941 version, the chapter "air" mentioned the concepts of oxygen, oxide and so on. In this stage, the teaching implementation related to redox reaction was closely related to the actual life and human social life. The versions of 1902 and 1904 roughly stipulated the general outline of chemistry teaching content, teaching equipment and classroom arrangement without clear indication of the specific teaching implementation and the ability that students should have. In the 1923-1948 version, the learning goal of redox reaction was that students can explain and analyze the phenomena of respiration, fire fighting, burning and iron rusting through observation or answering questions. In the 1948 to 1951 edition, through the study of redox reaction, it is emphasized that learning ability is the basic ability. With the conceptualization of redox reaction in chemistry, the concept of "redox" appeared in the teaching content of the curriculum standard of junior high school in 1948, but only in the form of concept, which did not describe how to teach. In the 1950 and 1951 version, a large number of related terms were added to the teaching content, including hydrogen reducing agent, metal reduction, carbon reducing iron, etc., but this only appeared in the form of nouns, only suggesting students to master chemistry concepts. In this stage, there were experiments related to redox reaction in the curriculum standard, but they were all in the form of independent concept, and it only required teachers to perform experiments, and the ultimate goal was still to point to the basic ability.

From 1954 to 2000, redox teaching did not only emphasized basic ability, but also increased experimental ability, scientific method and cognitive thinking ability in problem solving. In addition to adding a lot of chemistry concept to the teaching content, the CCCS in 1954 began to require students to conduct experiments, including the preparation of magnesium oxide and aniline oxidation. The 1988 edition requires students to understand redox reaction from the micro level, and understand that the essence of reaction is the gain and loss of electron. Moreover, students are required to conduct independent experiments to distinguish oxide and reducing agent by analyzing, comparing and summarizing the observed phenomena and understand their properties. Since then, in the study of redox reaction, students have been trained to learn scientific methods of chemistry. Students are required to understand and solve chemistry problems by connecting the observed macro phenomena with the particle movement in the micro world. From 2000 to 2017, the chemistry learning ability embodied in redox teaching includes basic ability, comprehensive ability, problem-solving ability, epistemology and creative thinking. Table 3 lists the chemistry learning abilities in the teaching cases about redox reaction in CCCS in 2017. It requires when learning redox reaction, students should not only master the basic concept and principle of the reaction, but also understand the scientific history of the source of the principle, and be able to use the principle to explain the phenomena in real life. So far, the chemistry learning ability required by the curriculum goal and teaching implementation of the curriculum content are basically consistent.

In summary, a century development of CCCS has gone through the stage of balanced development of discipline ability from the basic ability and epistemology as the main body to the problem-solving ability as the core, with epistemology as the support. In the curriculum standard, the chemistry learning abilities required for teaching implementation such as curriculum goals and contents are not the same. In the process of evolution in the past hundred years, most of the epistemology ability requirements, such as personality quality, emotional attitude and values, are not reflected in the documentary of teaching implementation. From 1948 to 2000, for nearly half a century, the practical application ability required in the curriculum goal has not been reflected in the specific teaching. In CCCS, the documentary of content only lists the chemical terms that students need to master one by one, and other teaching methods and activities to achieve this curriculum goals are not mentioned.

5. Discussion

Based on the previous theoretical research, we established the framework of Chinese chemistry learning ability (basic ability, comprehensive ability, problem-solving, epistemology and creative thinking) to study the development of chemistry learning ability of CCCS in the past hundred years. Research shows that learning abilities mentioned in Centennial CCCS tends to develop in a balanced way from a single separation and individualization to a pluralistic integration. However, the learning abilities required by the CCCS and teaching practice are not consistent. Many teaching implementation texts do not reflect the learning abilities mentioned in CCCS, especially the four sub abilities of epistemology. Because only the chemistry curriculum standards in mainland China are studied, there are some limitations in this study. The research results are not necessarily applicable to such liberal arts courses as Chinese, ideological and moral education. Moreover, due to the nature of China's national curriculum, the development of CCCS in the past century has its own national characteristics. However, this study has a great effect on the formulation and revision of chemistry curriculum standards in China and East Asia. And it can be used for reference for the research of chemistry learning abilities in international scientific education. Therefore, this study can provide some enlightenment in the aspects of research such as chemistry learning ability, chemistry curriculum goal making strategy, implementation path and values. It can be discussed as follows:

First, this paper studies the learning ability of chemistry from the perspective of policy documentaries. Based on the study of the documentaries of GOALS mentioned in the curriculum standard, the object of this study is the learning ability of chemistry, not the core competency. To some extent, core competency contains more content than learning ability, and has great influence on students. The middle school students' chemistry learning ability is the special ability, emotion, learning ability and learning method that students show after studying Chemistry (Lin , 2015). At present, most of the research is based on the qualitative analysis of existing concepts in policy documents, such as Bing Wei's research on 2017 senior high school chemistry curriculum standards in China. Bing Wei's research is based on the analysis of government's established core competency in the formulation process of educational policy documents and discourse analysis (Wei, 2019). This study is a theoretical framework based on the previous studies. Some Chinese scholars have also studied the changes of core competence in Chinese Physics Curriculum Standard of the past 100 years. This study, from the perspective of chemistry learning ability, provides a new way for the study of educational policy documentaries. In addition, it can be seen from our research that the chemistry learning ability required by the curriculum standard and the chemistry teaching practice is not consistent, especially in the area of epistemology ability. Kathleen M. Quinlan, a British scholar, once studied the personal morality and values in the discipline benchmark document formulated by QAA (Quality Assurance Agency), and found that different disciplines emphasized different qualities (Quinlan, 2016). Epistemology ability is related to the psychological changes of students' emotion and other non-intelligence factors, and how these factors are reflected in science curriculum is a very worthy research direction at present.

Second, when setting chemistry curriculum goals, different levels of learning abilities and interdisciplinary should be considered. In the evolution of chemistry curriculum, the dynamic development trend of students' learning ability is more and more obvious. Therefore, evidence-based research should be carried out based on the existing traditional experience. Through scientific and normative empirical research, the characteristics and laws of the chemistry teaching and learning process should be found to support the revision and implementation of the Chemistry Curriculum Standard. For example, they emphasized the early establishment of integrated science education with stem as the core, because many evidence-based studies showed that school curriculum learning experience has a great impact on students' interest in stem related subjects. Some researchers suggest that the integrated science education with STEM courses should be set up in the early stage. Many evidence-based studies show that school curriculum learning experience has a great impact on students' interest in STEM related subjects. For example, a five-year follow-up survey of more than 9000 primary school students and their parents shows that students' expectations and attitudes towards science are formed and solidified before the age of 14(Archer & Dewitt & Osborne & Dillon & Willis & Wong, 2012).The students' previous experience of integrated learning is the main predictor of their stem major selection and the quality of their later career(Archer & Dewitt & Osborne & Dillon & Willis & Wong, 2014). Therefore, the chemistry curriculum standard should build the level and interdisciplinary of students' learning ability through evidence-based research, and find out the teaching and learning rules of how to develop students' chemistry learning abilities.

Thirdly, teaching practice should be consistent with the goals mentioned in Chemistry Curriculum Standard and attention should be paid to the multiple paths from static knowledge, dynamic discipline practice to EQ cultivation. According to Posner's curriculum analysis model, curriculum standard belongs to "curriculum documentation", which guides curriculum construction and teaching practice (Posner, 2004).This study found that the part of teaching practice in the curriculum standard did not implement the goal requirements mentioned in the CCCS on students' learning ability. The teaching practice guidance part usually only has the chemistry discipline term, but lacks the goal implementation strategy and the process guidance. In Goodlad's theory (John.I.Goodlad) of curriculum implementation, curriculum implementation includes ideal curriculum, formal curriculum, comprehension curriculum, operation curriculum and experience curriculum(Li, 2010). Therefore, curriculum standards need to bridge the gap between the target text and the implementation text. Moreover, chemistry has scientific characteristics, which is different from humanities. It can't only rely on the description of concepts and laws to complete the requirements of curriculum objectives on students' learning ability. It needs to be achieved through specific teaching activities, teaching methods, experimental activities and other operational cases. Social and Emotional learning (SEL) is an important research field of Western pedagogy. The school, which combines the improvement of learning ability and the framework of social emotional development, can enhance the relationship between students and schools, classroom behavior and academic achievements (Guerra & Bradshaw, 2008). Therefore, CCCS should integrate static subject knowledge and dynamic subject practice with social and emotional learning, and explore suitable and effective educational path.

Fourth, People's values should be reflected in CCCS. In fact, the curriculum standard reflects the deep philosophical thinking of "what is human being" from the perspective of different disciplines. In fact, the chemistry curriculum goal also answers this question in the past one hundred years. The expression of CCCS should be optimized to reflect more real and advanced human learning concepts. We should understand and grasp people's values at a deeper and comprehensive level, and highlight the endogenous, process and relationship between people. Transfer from the teaching of knowledge to the cultivation of students' internal ability and character building. Pay attention to the regularity in the process of human learning and development. Start from the essence of human beings and construct the harmonious ecological relationship between human beings and the world (Long & Yu, 2012).In addition, the curriculum standard of chemistry in junior and senior high schools should also focus on the concept of sustainable development. However, the existing CCCS still reflects the sustainable development education in a general way. Teachers don't know how to apply it to classroom teaching. We should further manifest the goal of sustainable development education and promote its implementation.

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