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CONSTRUCTING CORE TEACHING COMPETENCY INDICATORS FOR SECONDARY SCHOOL SCIENCE TEACHERS IN CHINA

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Introduction

With the deepening of globalization and the rapid development of science and technology in today's world, the competition among various countries is increasingly intensified. In order to cope with the increasingly complex situations and problems in life and learning in the 21st century, students need to acquire and master the key competencies needed to future professions and careers during school (OECD, 2005, 2006; Tiana et al., 2011; Yao & Guo, 2018). The construction of teacher core competences is the key step to promote the development of core competences of students, and it is also the key to cultivating outstanding citizens who can adapt to globalization in the future. Many studies have shown that teacher competence has a positive effect on the formation of students' key competences (AACTE, 2016; Caena, 2014; Distler, 2007; Gordon et al., 2009). For example, Distler (2007) found that teachers' competences in organizing problem-based learning and implementing evidence-based teaching practice have a positive effect on critical thinking and clinical practice competences of nursing students. In report *Key Competences in Europe*, the Education and Culture Department of the European Commission pointed out that in the practice of competence-oriented curriculum reform, schools that have implemented quite successfully, a useful experience is that they all focus on the development of core teacher competences. In 2014, during the drafting of the *Education and Training: 2020 Plan*, Francesca, who was responsible for the research on teacher professional development, also realized that in terms of improving student learning and improving school effectiveness, teacher competence is always placed at the core, and excellent teachers should have the ability to cultivate excellent global citizens (Caena, 2014).

In the field of science education, we are in an era of striving for all students to achieve scientific literacy (one of the main goals of science education) (Bybee, 1995; NRC, 1996, 2012). In science teaching practice, the competent science teacher is the decisive factor for the success of students'



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Abstract. *Science teachers play a key role in successfully implementing science education reforms and providing all students with meaningful science learning opportunities. Therefore, what core teaching competencies do science teachers need to have in their practice? This study uses fuzzy Delphi technique and Analytic Hierarchy Process to approach the above problems. Experts from Chinese universities, secondary schools and educational research institutions were invited to participate in two rounds of Delphi process. The research results show that the four domains of core teaching competencies of science teachers and their 21 competencies have high content validity. Additionally, it can be concluded that the weights of core competencies of making learning objectives, raising pedagogical questions, stimulating learning motivation and analyzing course content ranked high, while the weights of core competencies of using information technology and multimedia, evaluating practical work, and presenting research results have received less attention. It is believed that the results of this study can enlighten the education reform of science teachers and promote the professional development of pre-service/in-service science teachers.*

Keywords: *teaching competence, science teacher, fuzzy Delphi, Analytic Hierarchy Process*

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science learning and the development of scientific key competences (Shaharabani & Tal, 2016). However, current school science disciplines, especially secondary school physics and chemistry, are not welcomed by students (Hofstein et al., 2011). This undoubtedly brings many difficulties to the teaching practice of science teachers and leads to the decline of the quality of science learning, and students' scientific literacy is ultimately difficult to be effectively developed. Davis et al. (2006) pointed out that science teachers in current school need to deal with the following challenges: understanding scientific disciplines and its subject matter; understanding of learners; understanding of teaching practice; understanding of learning environments and subject specialization.

Therefore, what are the key competences that a competent science teacher should have in dealing with these challenges and dilemmas? Eichinger (1992) pointed out that a competent science teacher should have interest in science; be competent in experimental demonstration and teaching; design experiments based on limited instruments and chemicals; have willingness to take time to prepare experiments and demonstrations, etc. Champagne and Hornig (1987) considered that a qualified science teacher should teach students to be productive and responsible citizens and generate student interests in science and prepare students to enter science as career. Bruce and Leonie (2006) found that the characteristics of the effective science teacher mainly include teaching methods, communications, enthusiasm, organizations, relationships between teacher and student, assessment of students, etc. Additionally, countries such as the United States and Australia have also enacted professional standards for the core teaching competencies of science teachers in secondary schools. For example, in *National Science Education Standards* (NSES), American science teachers' core teaching competencies such as implementation of inquiry teaching, evaluation of students' inquiry ability and educational research got attention (NRC, 1996). And Australian *National Professional Standards for Highly Accomplished Teachers of Science* pays special attention to science teachers' evaluation ability, inquiry-based teaching practice, digital literacy, and educational research skill as well (ASTA, 2002).

However, unlike the United States and Australia, which issued professional standards of core competences for science teachers, there is no textual standard for science teachers in China except a universal standard for both primary and secondary school teachers. Moreover, there are few studies on the core teaching competencies of secondary science teachers. Since the majority of secondary science teachers in mainland China are subject teachers (e.g., physics teacher, chemistry teacher) rather than integrated science teachers who usually undertake at least two science disciplines), the research on physics or chemistry teachers is much more common than that of integrated science teachers. Therefore, research on the core competences of middle school science teachers is of great significance to the regions that implement integrated science education in mainland China. It not only promotes the professional development of teachers in the regions where integrated science education is implemented, but also contributes to the construction of a core competences system and professional standard for science teachers in the future.

Theoretical Framework and Literature Review

The concept of *competence* aims at transferring attention from knowledge (especially declarative knowledge) to the application of skills, and it is the ability of the individual to apply knowledge and skills on a certain degree of independence and autonomy (Wuttke & Seifried, 2017). Mulder (2012) believed that competence has the following specific characteristics: it is the ability, talent, and potential of a person; it is a combination of knowledge, skills, and attitudes; it is a necessary condition for an individual to make an achievement; etc. McClelland (1973) argued that the school performance does not seem to have a real power in predicting real-world competence, that is, traditional intelligence tests do not always predict future job success. For a company or an organization, what makes the concept of competence really valuable is not trying to ensure that everyone is competent for every job, but to find an organization/job that suits the individual. Spencer and Spencer (1993) put forward the *Iceberg Model* of competence which consists of knowledge, skills, self-concept, traits, and motivation. The *Iceberg Model* provides a wider understanding of the connotation and characteristics of 21st century competence in various vocations and professions. Taking teacher competence as an example, it involves the sum of psychological qualities such as the knowledge, skills, and dispositions that teachers need to complete teaching tasks, and it reflects the potential of effective behaviors shown by teachers in response to specific pedagogic situations (Caena, 2014).

It should be noted that the term *competence* or *competency* lacks a consistent meaning in both the British and European linguistic traditions (Weinert, 2001). But there are also some basic consensuses, for example,



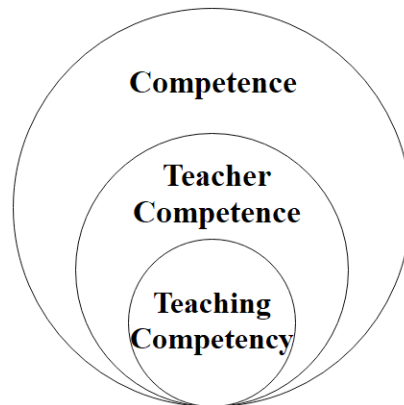
that “competence” (plural “competences”) is a broader term, while “competency” (competencies) refers to the different components of competence (Blömeke et al., 2015). It can be found that *competence* describes a complex feature from a holistic perspective, while *competency* has an analytical standpoint. In addition, both terms agree that a competence framework recognizes the nature of the performance requirements of certain fields in the real situation (Blömeke et al., 2015). Therefore, the definition of competence must start from the analysis of the real work context or education situation. Blömeke et al. (2015) considered competence as a horizontal continuum, which assumes that the whole is the sum of its (weighted) parts and divides competence into multiple constituents (latent abilities, skills) needed for competent performance. This study focuses on key teaching competencies (teaching competency), which places emphasis on components of competence from analytical stance.

Competencies can be understood as cognitive abilities and skills, which focuses on categorization and characterization of specialized cognitive competencies. Key Competencies of science teaching refer to clusters of cognitive prerequisites that must be available for a science teacher to plan, enact and evaluate his/her science teaching practice. Undeniably, the term competence includes knowledge, dispositions, domain-specific skills, which cover all of a person’s cognitive resources. Weinert (2001) pointed out that such a broad definition also has greatest disadvantage which people have confronted and have not been solved in the hundred years of scientific psychology: the integration of complementary classification and concrete performance of competence and knowledge. Therefore, the domain of science teaching competencies can be specialized and narrowly defined or very openly and widely defined.

In science education, pedagogical content knowledge (PCK) is an important part of science teachers’ knowledge system. Park (2008) considered that PCK comes from teaching practice and science teachers apply PCK in their teaching practice and emphasized that PCK includes teachers’ understanding and implementation. Veal and Makinster (1999) believed that PCK is competence that science teachers use a variety of strategies and evaluation methods to *translate* subject knowledge for different groups of students under the conditions of understanding the learning context, culture, and social constraints. Carlson and Daehler (2019) refined PCK in science education from the aspects of collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK), which integrated PCK (e.g., discipline, topic, concept) and competence (planning, enacting, reflecting, and evaluating) based on the educational context and practice. Obviously, different scholars have different understandings on whether PCK is knowledge or competence. After sorting out various viewpoints, this study believes that PCK is the knowledge owned by teachers, and only after teachers have the knowledge of students’ understanding, teaching strategies and evaluation, can they demonstrate those core competencies in the teaching plan or the instruction enactment. And science teachers can successfully apply core teaching competencies across a maximum number of different tasks based on their classroom experiences and context.

To sum up, *teacher competence* involves implicit and explicit knowledge (e.g., PCK, subject matter, assessment knowledge), cognition, practical skills, and dispositions (motivation, belief, value orientation and emotion), and *teaching competency* reflects the core competencies of secondary science teachers to cope with various daily teaching situations. The former describes a complex feature from a holistic perspective, while the latter places emphasis on components of competence from analytical stance. Besides, in order to clarify the relation among teaching competency, teacher competence and competence, Figure 1 is presented. As can be seen in Figure 1, in terms of the subordination relation among them (teaching competency, teacher competence and competence), the former is subordinate to the latter respectively, and the latter involves a broader and systematic professional concept, which is universal and general. For example, Sudirman (2017) divided teacher competence into teaching/pedagogical competency, individual competency, social competency, and professional competency. Similarly, Green and Osah-Ogulu (2003) identified three categories of teacher competence: intellectual competency, environmental competency, and pedagogical competency. As the mentioned above, the scope of the concept of teacher competence is wider than that of teaching competency.



Figure 1*The Subordination among Competence, Teacher Competence, and Teaching Competency**Teacher Competence*

The European Teacher Competence Framework (ETCF) describes the concept of teacher competence as follows: *it involves implicit and explicit knowledge, cognition, practical skills, and dispositions (such as motivations, beliefs, values and emotions); it can meet the complex needs of teachers (for example, teachers can make them behave professionally and appropriately in specific situations by mobilizing psycho-social resources); it can ensure that teachers carry out their tasks effectively and the tasks were completed efficiently, and can continuously represent the specific level of individual achievement* (Caena, 2014). Teacher competence is interdisciplinary and multifunctional and plays an important role in the realization of many important goals and helps individual deal with different tasks, and transfer in unfamiliar situations (Caena, 2014).

Many scholars have defined and studied teacher competence. For example, Bieri (2011) proposed that teacher competence should include five dimensions such as communication, cooperation, self-confidence, motivation, and fact-finding. Kaendler et al. (2015) divided teacher competence into professional knowledge, teacher beliefs, the ability to plan interaction, monitor, support, and consolidate interaction, and reflect. Zhu et al. (2013) validated core competences related to teachers' innovative teaching, and carried out four competences: learning competence, educational competence (such as responsibility, love, sensitivity and so on), social competence and technological competence. It can be found that the definition and connotation of teacher competence is comprehensive and integrative (such as knowledge, skills, behavior, skills, self-concept, dispositions, etc.), and it is a complex psychological quality that must be mastered for individual cognition, social interaction, and professional achievement (Bieri & Schuler, 2011; Mulder, 2001; Wuttke & Seifried, 2017).

Teaching Competency

Teaching competency is directly related to pedagogical skills, and it is all the repertoire that a teacher must master in dealing with different teaching situations (Caena, 2014). Tigelaar et al. (2004) pointed out that the traditional teaching competency framework mainly involves teaching methods, demonstrating skills, guidance and suggestion skills, and skills of designing course materials. Many researchers have conducted empirical studies on teaching competency. For example, Bawane and Spector (2009) divided teaching competencies into designing strategies, selection of appropriate learning resources, implementing teaching strategies, encouraging students to participate in cooperation and helping students maintain motivation. Gilberts and Lignugaris-Kraft (1997) presented five categories in instruction competencies such as preparation for specific instructional activities, presentation of material, feedback and praise, interactive assessment, and effective use of time.

In addition to the above-mentioned research on teaching competencies, there are also many studies on teaching competencies from the perspective of teachers' roles. For instance, Tigelaar et al. (2004) constructed teaching competency through the Delphi method from the perspective of roles: teacher as individual, subject

knowledge expert; facilitator of learning (such as learning evaluation) and scholar/lifelong learners. Carril et al. (2013) divided teaching competencies into the following five roles: designers and developers (designing teaching plans and strategies, developing learning resources, implementing teaching plans and strategies, and designing evaluation activities); subject content experts (developing courses); mentors (organizing and promoting various teaching practices); professionals (communication, update knowledge, attitude, and participate in professional development projects). It can be found that studies on teaching competencies all attach importance to core skills before or during the teaching practice of science teachers, such as preparation and planning skills, implementation and practical skills, evaluation skills, etc.

Science Teacher Competence

Since the 1960s, many scholars have studied the competence of science teacher (Alake-Tuenter et al., 2012; Butzow & Qureshi, 1978; Mulder, 2014; Spore, 1962; Tulloch, 1986; Green & Osah-Ogulu, 2003). Butzow and Qureshi (1978) got 12 indicators of competence of science teacher: knowledge, good relationship between teachers and students, identification of individual differences, creation of vivid classrooms, subject competence, instructional design, critical thinking, etc. Alake-Tuenter et al. (2012) considered competence of science teacher as an individual comprehensive performance-oriented capacity, including a large number of knowledge structures and cognition, effective and necessary mental abilities, attitudes and values. And these elements play a role in performing tasks, solving problems, and in a profession, organization, position, or role. Alake-Tuenter et al. (2013) identified three core elements of competence of science teacher including subject matter knowledge, pedagogical content knowledge, and attitude. For another example, Sedibe et al. (2014) conducted structured interviews to explore the competence of science teacher in senior township schools in Soweto, Gauteng Province, and the results showed that these science teachers highly identify with the following three competences: enthusiasm for science teaching, qualifications and experience of science teaching, and supportive teaching materials. Through the above literature, it is found that the competence of science teacher mainly involves the following components: knowledge, teaching skills, attitudes, values and so on.

Science Teaching Competency

In addition to the research on the competence of science teacher, there are scholars who have conducted empirical research on the teaching competencies of science teacher. De Putter-Smits et al. (2012) pointed out that the teaching focus of STEM disciplines or scientific subject matter should be intended to develop teaching competencies of science teacher. And teaching competencies in science education mainly include teaching practice, preparedness, engagement with students and learning of evaluation (Deacon et al., 2017). The Science Teacher Education Committee of the United States (1974) obtained 23 basic elements of teaching competencies of science teacher such as evaluating student achievement, selecting and designing teaching materials, clarifying courses and units of learning objectives, and directing practical work, etc. De Putter-Smits et al. (2012) divided the teaching competencies of science teacher into five dimensions: context handling, regulation, emphasis, design, and school innovation. Wu et al. (2018) developed a questionnaire to investigate science/math teachers' perceptions of their professional teaching competencies, which mainly include providing students a cooperative learning environment, capable of raising students' attitudes toward math/science, etc.).

Based on the above literature review, it can be found that the teaching competencies of science teacher studied by researchers mainly involved three domains: pedagogical design (such as analyzing course content and students, making learning objectives, designing activities, etc.), teaching implementation (such as organizing scientific inquiry, using information technology and multimedia, encouraging cooperation, etc.), and learning evaluation (evaluation of the learning process and feedback). In this study, the fourth domain of *teacher research* was added. McClelland (1973) stated that competence refers to the deep-level personal characteristics that can distinguish outstanding accomplishers from ordinary work. From this point of view, teacher research is an important domain of teaching competencies of science teacher. In *National professional standards for highly accomplished teachers of science*, the Australian Science Teachers Association points out that *highly accomplished science teachers are active in professional communities outside schools, writing articles for journals, participating in research projects...* Stenhouse (1981) proposed the concept of teacher research, that is, teachers conduct research on their own practice, teaching, and student learning in a systematic way. Zhu and Wang (2014) considered educational research ability as one of teachers' key



competence. In order to avoid personal subjective judgments and predict which competences should be paid attention to in the teaching competencies of a science teacher, we chose the Delphi technique for this research.

Research Problem

However, as a topic in the field of science education research, the focus of science teacher mainly involves PCK (Shulman, 1986 & 1987), views on nature of science (Lederman, 1992; Abd-El-Khalick & Lederman, 2000), dispositions (Flores, 2016), and few research studies on the core teaching competencies of science teachers (Ye et al., 2019). And even if it is competence research about science teacher, the research objects are mainly about elementary science teacher or pre-service science teacher (Deveci, 2016; Wu et al., 2018), and there are few studies for secondary school science teachers. Moreover, most of the research on (science) teacher competence only focuses on the acquisition and extraction of the competences components, instead of further comparing the relative importance (weights) of these competences to obtain more in-depth results and conclusions. In a word, unlike the international science education research that has always emphasized science courses, conceptual learning, and scientific literacy research, there is less attention paid to the research on the competence of secondary school science teachers (Ingersoll, 2011).

Given the above analysis and consideration, this study raised the following two questions:

- (a) What are the core teaching competencies should secondary school science teachers possess?
- (b) What is the relative importance (weights) among these core competences?

This study used fuzzy Delphi technique and Analytic Hierarchy Process to explore the above questions. Therefore, the study aimed to identify core competences related to science teaching that secondary science teachers should be equipped with through the authority decision processes by expert community. It is expected that the results of the study can enlighten the education reform of science teachers and promote the professional development of pre-service/in-service science teachers.

Research Methodology

The fuzzy Delphi technique is an improved experts' decision-making method that introduces the fuzzy mathematic theory into the Delphi research. There are many disadvantages in the implementation of Delphi technique. For example, the implementation period is too long, and it is costly to complete the entire research through multiple rounds of repeated surveys. Moreover, the answers and feedback of experts are ambiguous and uncertain. In order to solve these problems, Murray et al. (1985) combined the Delphi technique and fuzzy set to reduce the ambiguity of the Delphi technique. Additionally, Kaufmann and Gupta (1988) proposed another more complete fuzzy Delphi process, which uses fuzzy set theory and requires participants to give three evaluation values (conservative value, optimal value, and optimistic value), and then form a Triangular Fuzzy number (TFN) and calculate their geometric means. The advantage of TFN is that it can make up for the occurrence of extreme values and enhance the effect of indicator selection (Ishikawa et al., 1993). And fuzzy Delphi technique usually requires only one or two round consultation based on Triangular Fuzzy number (Lin & Lu, 2013; Saido et al., 2018).

Analytic Hierarchy Process is a decision-making method used to deal with multi criteria problems and can handle tangible and intangible factors. Its main feature is that it can reasonably combine qualitative and quantitative decision-making, and hierarchize the decision-making process based on individual thinking and psychological patterns and can summarize multi-factor problems or complex multi-criteria into a hierarchical structure. Saaty (1977) pointed out that the hierarchy is a representative structure of complex problems in a multi-level hierarchical structure. By using a hierarchical structure, you can describe a specific problem in different groups, and then organize it into a hierarchical structure, so that the problem becomes more structured and systematic. Analytic Hierarchy Process is the result of the selection criteria and is dominated by the deepest sub-criteria. Moreover, it attaches importance to validity. If the inconsistency exceeds a certain threshold, the decision-maker will make a new choice from various standards and alternatives.

Participants

The selection of experts is the key step to ensure the quality of Delphi research (Wan & Bi, 2020). Before starting the consultation and investigation formally, this research explained to each expert the purpose and necessity



of this research and the time required to participate in the research and promised that their participation in this project must volunteer, and to ensure that the experts' personal information is kept confidential and will not be disclosed to others or other purposes. The number of experts may vary from 10 to 50 (Saido et al., 2018; Wan & Bi, 2020). In this study, a total of 30 experts was invited successfully, including 10 science teachers, 8 science education administrators, and 12 university professors (See Table 2). All experts at least meet the following three or more criteria: (1) professor title; (2) at least 20 years of working experience in secondary school science teaching, science learning research or science teacher research; (3) domestic and foreign papers or academic works in science education; (4) principal or vice principal; (5) experience of trainer in science teachers' professional development. The collected expert questionnaires were reviewed. A total of 28 questionnaires met the response requirements, and the effective rate of the questionnaires was 93.33%. The invalid questionnaire was judged as the obvious regularity of the answers, and the answers did not conform to the logic and requirements of this study (for example, the three types of values must conform to the minimum value \leq the optimal value \leq the maximum value).

Table 1*Demographics of 30 Experts*

Region	Gender		Seniority		Title	
	Province/City	Male	Female	20-30	≥ 30	Professor
Anhui		2	1	1	2	3
Beijing		3	2	0	5	5
Fujian		2	0	0	2	2
Hainan		1	0	0	1	1
Jilin		1	0	1	0	1
Jiangsu		3	0	2	1	3
Jiangxi		1	0	0	1	1
Shanghai		1	0	0	1	1
Shan'xi		1	0	1	0	1
Shandong		6	2	4	4	8
Shanxi		0	1	1	0	1
Zhejiang		3	0	2	1	3
Total		24	6	12	18	30

Instruments

The items of instruments in this study were selected based on literature reviews and existing research results (Table 2). Specifically, the first domain (Pedagogical Design) mainly involves competences: analyzing course content (ACC), analyzing students (AS), making learning objectives (MLO), arranging procedures and steps (APS), designing activities (DA), and choosing strategies and tools (CST). The second domain (Teaching Implementation) includes stimulating motivation (SM), establishing learning context (ELC), directing practical work (DPW), organizing scientific inquiry (OSI), using information technology and multimedia (UIM), and encouraging cooperation (EC). The third domain (Learning Evaluation) includes evaluation of learning process (ELP), evaluation of academic achievement (EAA), evaluation of practical work (EPW), and feedback of evaluation (FE). And the fourth domain (Teacher Research) mainly covers competences such as raising questions (RQ), collecting data (CD), developing plan (DP), implementing protocols (IP), and presenting research results (PRR).

The instruments in this study were mainly divided into two categories: the fuzzy Delphi questionnaire and the Analytic Hierarchy Process questionnaire. Except for differences in format and structure, the contents of the two types of questionnaires are basically the same, and there are no major differences. The fuzzy Delphi questionnaire adopts 0-10 rating mode, and the participants need to give three values for each item independently. Analytic



Hierarchy Process questionnaire adopts the scoring mode of 1-9. Participants need to compare each pair of items in pairs and give the relative importance value. The questionnaires in this study consist of 21 items, and the structure of the questionnaire includes the following four parts: introduction, filling instructions, filling examples and filling items. Based on the questionnaire data of 30 experts, the overall Cronbach alpha coefficient of the questionnaire is .919, indicating that the scale had a high reliability.

Data Analysis

Fuzzy Delphi technique

The data processing and analysis of fuzzy Delphi questionnaires mainly aims to check whether the opinions among the experts are consistent and calculate the value of the consensus significance G^i for each criterion. It includes the following three steps: **Step 1:** If \leq , it means that the expert group has consensus on the item. **Step 2:** If $>$, and the gray zone interval value (Z^i) is smaller than the interval value (M^i). It shows that in the presence of a tiny gray fuzzy space, but the experts who give extreme opinions will not be too different from other experts, so there is no divergence of opinions. **Step 3:** If $>$, and the gray zone interval value (Z^i) is greater than the interval value (M^i). It indicates that some experts put forward extreme opinions very different from others. Therefore, it is necessary to conduct another round of questionnaire survey on these evaluation items that have not reached convergence. After two rounds questionnaire surveys, if the evaluation item fails to reach the convergence standard, it will be deleted.

Analytic Hierarchy Process

Analytic Hierarchy Process analysis generally goes through the following steps: **Step 1:** Construct an Analytic Hierarchy Process questionnaire to collect data (this was done with the help of fuzzy Delphi technique). **Step 2:** Calculating the geometric means based on Analytic Hierarchy Process questionnaires and constructing the total judgment matrix. The purpose of this section is to integrate the opinions of all the experts. **Step 3:** Consistency testing is necessary to use Analytic Hierarchy Process research, so it is necessary to determine whether the pairwise comparison matrix is consistent. The indicators mainly involve the use of Consistency Index (CI) and Consistency Ratio (CR). CR is used to measure how far the decision-makers' judgment is from the critical value of the consistency of fitting. CR is obtained by dividing the consistency index (CI) by the random index (RI). If $CR < 0.1$, it means that the actual judgment matrix has high consistency (Saaty, 1977). **Step 4:** Determine the global weight of each domains and behavioral indicators accordingly.

Table 2

Core Teaching Competencies and Characteristics for Secondary School Science Teacher

Domains	Competences	Alake-Tuenter et al. (2012)	Aydeniz & Dogan (2016)	Beasley (1982)	Bell & Cowie (2001)	Beyer & Davis (2012)	Butzow & Qureshi (1978)	Castle (2006)	Cheng (2014)	Davis et al. (2011)	Dobber et al. (2012)	Forbes & Davis (2010)	Hensiek et al. (2017)	John (2006)	Klein & Jun (2014)	Simpson & Brown (1977)	Stenhouse (1981)	Tulloch (1986)	Willelems et al. (2017)	Wu et al. (2018)	Zhang et al. (2017)	Zhu et al. (2013)
	ACC				○			○					○	○							○	○
	AS				○			○	○				○	○							○	
Pedagogical Design	MLO				○			○	○				○	○							○	
	APS				○																○	○
	DA												○								○	
	GST				○			○					○	○							○	○



Domains	Competences	Alake-Tuenter et al. (2012)	Aydeniz & Dogan (2016)	Beasley (1982)	Bell & Cowie (2001)	Beyer & Davis (2012)	Butzow & Qureshi (1978)	Castle (2006)	Cheng (2014)	Davis et al. (2011)	Dobber et al. (2012)	Forbes & Davis (2010)	Hensiek et al. (2017)	John (2006)	Klein & Jun (2014)	Simpson & Brown (1977)	Stenhouse (1981)	Tulloch (1986)	Willegens et al. (2017)	Wu et al. (2018)	Zhang et al. (2017)	Zhu et al. (2013)
Teaching Implementation	SM	○				○										○				○		
	ELC	○																			○	
	DPW					○						○										
	OSI	○		○		○						○				○					○	
	UIM			○		○						○				○						○
	EC	○				○										○					○	○
Learning Evaluation	ELP		○		○		○											○				○
	EAA				○		○											○				○
	EPW												○									
	FE		○	○			○						○									
Teacher Research	RQ							○									○		○			○
	CD							○			○						○		○			○
	DP										○						○		○			
	IP							○									○		○			
	PRR							○			○						○		○			

Research Results

Consensus Analysis of the Experts

Table 3 and Table 4 shows the results of the fuzzy Delphi survey of the four domains and their core competences in science teaching accordingly. The calculation of fuzzy Delphi questionnaire shows that, taking "T1-1" as an example, the minimum and maximum of the most optimistic value () given by the expert community on the domain of pedagogical design is 8 () and 10 () respectively. Then, calculate the arithmetic mean of the experts' of the competence, which is 9.00, and the standard deviation (SD) is 0.49, and delete extreme values that greater than or less than twice the SD (9.00±0.98). In this example, experts' optimistic values are all within twice the SD, and so all items are retained. Then calculate the geometric mean value to establish the triangular fuzzy number = (8, 9.00, 10) for the most optimistic value. Similarly, establish the triangular fuzzy number = (5, 6.39, 8) for the most conservative value. Then, the Grey Area Method is used to test whether the expert community has reached a consensus on item T1-1. In this example (T1-1), there is no overlap between the two triangular fuzzy numbers (≤), indicating that there is a consensus of the expert opinion interval value, and it turned out items T1-1 have reached convergence. Besides, items like T1-3, T1-4, T1-5, T1-6, T2-1, T2-2, T2-3, T2-4, T2-5, T3-2, T3-4, T4-1, and T4-4 also meet the above requirements and retain these items. Currently, the consensus degree value between experts: $G^i = ()/2 = 7.70$.

However, the two triangular fuzzy numbers of T1-2, T2-6, T3-1, T3-3, T4-2, T4-3 and T4-5 overlap, and the gray area ($Z^i = -$) is less than the interval between the expert's geometric mean of "the most optimistic value" and "the most conservative value" ($M^i = -$), i.e., ($Z^i < M^i$), indicating that the opinion interval value of each expert has no consensus section. It means that although the opinion interval value of each expert has no consensus section, the two experts who gave extreme value opinions (the most conservative value in optimistic value and the most optimistic value in conservative value) did not differ too much from other experts, leading to diverging opinions. At this time, the consensus degree $G^i = -$. It can be found from Table 3 that the expert consensus value of these 7



items is between 7.35 and 7.50. The threshold value of G^i in this paper is set to 6.5, which has been accepted by more than 80% of experts.

Table 3
Report of Four Domains of Core Teaching Competencies of Science Teachers

Code	Domains	O^i_L	O^i_U	C^i_L	C^i_U	O^i_M	C^i_M	M^i	Z^i	$M^i - Z^i$	G^i
T1	Pedagogical Design	7	10	4	7	9.02	6.10	2.92	0	2.92	7.56
T2	Teaching Implementation	7	10	4	7	9.09	6.13	2.96	0	2.96	7.61
T3	Learning Evaluation	7	10	3	7	8.59	5.88	2.71	0	2.71	7.24
T4	Teacher Research	7	10	3	7	8.59	5.87	2.72	0	2.72	7.13

Determine the Weights of All Domains and Competences

Table 5 shows the judgment matrix constructed by experts for the four domains of science teaching competence: for example, the importance of pedagogical design was 1.28 times that of teaching implementation, and the importance of teacher research was 2.3193 times that of learning evaluation, and the importance of teaching implementation was 2.7473 times that of learning evaluation, and so on. Finally, through the weights' average statistical results, it can be seen that the weights of the four core domains of science teaching competence were: pedagogical design (36.69%) > teaching implementation (28.67%) > teacher research (24.20%) > learning evaluation (10.44%).

Table 4
Report of Core Teaching Competencies of Science Teachers

Domains	Competences	O^i_L	O^i_U	C^i_L	C^i_U	O^i_M	C^i_M	M^i	Z^i	$M^i - Z^i$	G^i
Pedagogical Design	T1-1	8	10	5	8	9.00	6.39	2.91	0	2.91	7.70
	T1-2	7	10	4	8	8.75	6.01	2.74	1	1.74	7.47
	T1-3	8	10	5	8	9.24	6.58	2.66	0	2.66	7.91
	T1-4	9	10	5	8	9.35	6.68	2.62	-1	3.62	8.02
	T1-5	8	10	5	8	9.19	6.63	2.56	0	2.56	7.91
	T1-6	7	10	5	7	8.64	5.69	2.95	0	2.95	7.12
Teaching Implementation	T2-1	8	10	5	8	9.41	6.54	2.87	0	2.87	7.98
	T2-2	8	10	5	8	9.33	6.48	2.85	0	2.85	7.91
	T2-3	8	10	5	8	9.33	6.57	2.73	0	2.76	7.95
	T2-4	8	10	4	8	9.32	6.39	2.93	0	2.93	7.86
	T2-5	7	10	4	7	8.57	5.23	3.24	0	3.24	6.93
	T2-6	7	10	4	8	8.82	5.94	2.88	1	1.88	7.47
Learning Evaluation	T3-1	7	10	4	8	8.45	5.60	2.85	1	1.85	7.38
	T3-2	7	10	5	7	8.30	5.78	2.52	0	2.52	7.04
	T3-3	7	10	3	8	8.75	5.98	2.77	1	1.77	7.46
	T3-4	8	10	5	8	8.87	6.18	2.69	0	2.69	7.53
Teacher Research	T4-1	8	10	4	8	9.01	6.15	2.86	0	2.86	7.58
	T4-2	7	10	4	8	8.53	5.70	2.83	1	1.83	7.40
	T4-3	7	10	3	8	8.45	5.60	2.85	1	1.85	7.38
	T4-4	7	10	5	7	8.44	5.78	2.77	0	1.77	7.11
	T4-5	7	10	5	8	8.54	6.13	2.41	1	1.41	7.45

Table 5*Weight Analysis of Four Domains*

Domains		T1	T2	T3	T4	Weight	Rank
Pedagogical Design	T1	1	1.2800	3.5165	1.5162	36.69%	1
Teaching Implementation	T2	0.7813	1	2.7473	1.1846	28.67%	2
Learning Evaluation	T3	0.2844	0.3640	1	0.4312	10.44%	4
Teacher Research	T4	0.6595	0.8442	2.3193	1	24.20%	3

 $CR < 0.1$.

Table 6 shows the ranking of the weights of 21 competences for core teaching competencies of science teachers in middle schools, including the intra-group weights and overall weights, as well as the intra-group rankings and overall rankings.

In the domain of pedagogical design, the weights of key competences ranked below: make learning objectives (27%) > analyze course content (22%) > analyze students (20%) > design activities (13%) \approx arrange procedures and steps (13%) > choose strategies and tools (5%). The rank of weight in developing educational **objectives**, analyzing course content and analyzing students was in the top 3, and their weights in the group all exceed 20% accordingly, indicating the importance of these elements in the teaching preparation stage before the teacher's teaching implementation. Moreover, the competence of developing educational objectives (9.99%) ranked first among the 21 competences, and the competence of analyzing course content and analyzing students also rank very high in the overall ranking.

Table 6*Weight Analysis of Overall Competences*

Domains	Competences	Weight (%)	Rank	Overall Weight (%)	Overall Rank
Pedagogical Design CR < 0.1	Analyze course content	22	2	8.14	4
	Analyze students	20	3	7.40	5
	Make learning objectives	27	1	9.99	1
	Arrange procedures and steps	13	5	4.81	
	Design activities	13	4	4.81	
	Choose strategies and tools	5	6	1.85	
Teaching Implementation CR < 0.1	Stimulate motivation	31	1	8.99	3
	Establish learning context	24	2	6.96	
	Direct practical work	12	4	3.48	
	Organize scientific inquiry	20	3	5.80	
	Use information technology and multimedia	4	6	1.16	
Learning Evaluation CR < 0.1	Encourage cooperation	9	5	2.61	
	Evaluation of learning process	26	2	2.60	
	Evaluation of academic achievement	32	1	3.20	
	Evaluation of practical work	19	4	1.90	
	Feedback of evaluation	23	3	2.30	



Domains	Competences	Weight (%)	Rank	Overall Weight (%)	Overall Rank
Teacher Research CR< 0.1	Raise questions	41	1	9.84	2
	Collect data	11	4	2.64	
	Develop plan	22	2	5.28	
	Implement protocols	16	3	3.84	
	Present research results	10	5	2.40	

In the domain of teaching implementation, the weights of key competences ranked below: stimulate motivation (31%) > establish learning context (24%) > organize scientific inquiry (20%) > direct practical work (12%) > encourage cooperation (9%) > use information technology and multimedia (4%). The rank of weight in stimulating motivation, establishing learning context and organizing scientific inquiry was in the top 3, and their weights in the group all exceeded 20%, indicating the importance of these elements in the teaching practice of science class. Moreover, the competence of stimulating motivation (8.99%) ranked the third among the 21 competences, indicating the importance of stimulating students' motivation in teaching practice.

In the domain of learning evaluation, the weights of key competences ranked below: evaluation of academic achievement (31%) > evaluation of learning process (26%) > feedback of evaluation (23%) > evaluation of practical work (19%). It can be seen that the evaluation of scientific learning achievements is much more important than other factors, and the emphasis on practical work and evaluation feedback are relatively insufficient. Additionally, the weights of the four key competences in the evaluation domain were relatively low in all 21 competences, which reflects the distinct disadvantage of evaluation in the current Chinese science teaching to a certain extent.

In the domain of teacher research, the weights of key competences are ranked below: raise questions (41%) > develop plan (22%) > implement protocols (23%) > collect data (16%) > present research results (11%) > collect data (10%). It can be seen that raising questions is much more important than other factors, and the emphasis on presenting research results is relatively insufficient. Moreover, the competence of raising questions (9.84%) ranked second among the 21 competences, indicating the importance of raising questions in pedagogical research.

Experts' Views on Teaching Competencies of Science Teacher

Some experts put forward their opinions and suggestions on the specific content of core teaching competencies during the fuzzy Delphi research. These recommendations are sorted out and collated, which provides an important basis for the follow-up investigation of Analytic Hierarchy Process. For example, Expert ZKL pointed out that *secondary school science teachers can use the novel information technology in science classrooms*. And expert YBJ believes that *secondary school science teachers should be able to integrate skillfully science and technology into the scientific learning environment*. These two experts pay special attention to the competence of science teachers to integrate science and technology with science teaching practice. Taking information and communication technology as an example, the rapid development of internet technology in the 21st century has promoted the popularization of information and communication technology in science teaching and learning. Information and communication technology not only enriches the learning environment of science classrooms, but also puts forward a more comprehensive ability demand for science teachers to integrate educational technology and teaching practice (Kadioglu-Akbulut et al., 2020). Science teachers with digital literacy must not only cultivate students' information and communication literacy, but also help students' peer collaboration and problem solving in the internet environment, which will ultimately enable students to develop into innovative and creative 21st century learners (Alt, 2018). Expert DYX states that *secondary school science teachers should be able to make some innovative practical works*, and WQH also considers that *improvement and innovation of demonstration experiments is the important competence that secondary school science teachers need to possess*. It can be found that both experts agree that secondary school science teachers' experimental ability is very important. The research of science teachers' practical work has always been a key direction in the research field of science teachers, and it has received the common attention and attention of scholars in different science education fields.



Discussion

Science teachers play a key role in successfully implementing science education reforms and providing all students with meaningful science learning opportunities (Chin, 2006). Although the research on improving and enhancing the classroom teaching efficiency of middle school science teachers has received extensive attention in the past few decades, front-line science teachers still face many problems and difficulties (Davis et al., 2006). Undoubtedly, science teachers are the most dominant intersection between science curriculum and the improvement of individual scientific literacy. As an important part of the competence structure of science teachers, teaching competence is an indispensable capacity for science teachers to implement and carry out classroom teaching. For example, the Analytic Hierarchy Process results showed that the weights of learning evaluation and teacher research, as well as their core competences have low weights. However, the weights of pedagogical design and teaching implementation, as well as their core competences, are much higher.

Firstly, in the domain of pedagogical design, which ranks first among the four domains. The domain of pedagogical design represents the ability of science teachers to connect teaching theory with teaching practice activities and has a potential impact on the development of students' scientific capacities such as scientific argumentation and scientific reasoning (Knightbardsley & Mcneill, 2016). Specifically, it can be seen from Table 6 that the competence of making learning objectives ranks first among the six core competences, which is consistent with the existing relevant research results. For example, Zhang et al. (2017) found that pre-service biology teachers performed significantly better than biological technology students (non-teacher) in making learning goals ($p < .05$), but there is no significant difference in other core competencies in the domain of instructional design. Additionally, Klein and Jun (2014) surveyed 82 teachers with master's or doctoral degrees in instructional system of Florida State University, and the result turned that none of the respondents considered aligning objectives and preparing goals as unimportant, while more or less some of the subjects considered other competence indicators in the field of instructional design as unimportant. As one of the competences of teaching design, setting learning objectives is an indispensable skill for science teachers in the process of teaching design. Beyer and Davis (2012) also pointed out making learning goals and establishing lesson purpose play a significant role in pedagogical design for science teacher.

Secondly, in the domain of teaching implementation, it can be seen from Table 6 that the competence of using information technology and multimedia, encouraging cooperation, and directing practical work ranks in the bottom three, respectively. To a certain extent, this reflects the ignorance of the importance of these competences by science teachers in mainland China. Taking the using information technology and multimedia as example, it's not just about the teachers' ability to use digital resources, and it's about cognitive skills and social emotional skills involved in performing tasks and solving problems in a digital instructional environment (Van Laar et al., 2017). International organizations attach great importance to the development of teachers' information technology competence. For example, UNESCO promulgated an information technology Competency Framework for Teachers (ICT-CFT) in 2008 and issued the second edition of ICT-CFT in 2011, which aims to help different countries develop national level teacher information technology competence training strategies and standards. However, the weight of using information technology and multimedia in the six core competences is only 4% (see Table 6), far below the average weight of 17%. Deng et al. (2014) found that high school teachers' overall performance in using information technology is poor in China. The secondary school science curriculum is more closely related to science, technology, engineering, and the environment (Wan & Bi, 2020). Therefore, education administrators, teacher educators and science teachers need to take the competence of using information technology seriously, and deeply explore the professional development in using information technology and multimedia.

For another example, the competence of encouraging cooperation, its weight in the six core competences is only 9% (see Table 6), and far below the average weight of 17% as well. Cooperative learning emphasizes social interaction, which is a process of multi-directional in-depth communication between teachers and students, students and students, and is an effective learning method that has a positive impact on students' academic achievement (Guiller, Durndell, & Ross, 2008). However, the current school curriculum is loaded with too many concepts and knowledge, and students are often told that they only need to repeat and mechanically memorize these concepts, which makes it easy for students to understand them only at a superficial level. Cooperative learning is based on face-to-face social interaction, focusing on the development of critical thinking and communication skills. Guiller et al. (2008) stated that critical thinking is a collaborative learning process in which students construct knowledge through argumentation and discussion of various ideas and concepts. Traditional cooperative learning is carried



out in the form of face-to-face social interaction. With the continuous popularization of internet technology, information technology and multimedia provide new ways to promote cooperative learning and the development of individual critical thinking and communication skills (Jang, 2014). Internet-based cooperative learning brings many conveniences to education (such as low cost, high efficiency, convenience, etc.), and with the continuous popularization of virtual reality technology, augmented reality technology, and holographic technology, internet-based cooperative learning brings more vivid and intuitive experience to individuals (Lopezperez et al., 2011). For teachers, the ICT-CFT framework points out that it is not enough for teachers to only possess information technology skills and impart it to students, and they also need to use information technology to help students become cooperative, problem-solving, and creative learners.

Thirdly, in the domain of learning evaluation, it is the field that science teacher least takes seriously (see Table 6). Similarly, the gap among its core competences is not very large overall, and these competences are not ranked high among all elements (see Table 6). According to the results of experts' weight assignment of teaching competencies of science teacher, science teachers in China do not attach great importance to individual science learning evaluation, and especially to its core competences such as the evaluation of students' practical work and their feedback. The biggest challenge in evaluating science learning is the cost (such as time, intelligence, labor, etc.) involved in designing and developing the evaluation. While higher-level skills such as critical thinking can be assessed using multiple-choice questions, science learning tools should not be limited to multiple-choice tests, but should also be used to assess creativity, and even use collaboration to complete the assessment (Pacific Policy Research Center, 2010). However, in China, especially high school science teachers, they often need to undertake a large number of teaching tasks. Generally, each teacher independently undertakes 3-4 classes of science teaching tasks (such as physics, chemistry, biology, etc.). The average number of students in each class will be around 50 or more, which brings great challenges to science teachers to carry out the assessment work for students' science learning. The earliest implementation of systematic and large-scale evaluations on scientific literacy in the world mainly includes the PISA and TIMSS, which mainly involves real contexts, subject matter, scientific attitude, and scientific practice and so on. At present, science academic testing in China has not formed a mature framework. The main reason lies in that science course and science ability assessment are not included in the core academic evaluation system, and science teaching has not got rid of the traditional teaching model. In view of this, science teacher in China should focus on students' scientific knowledge and ability from different dimensions in the evaluation, so as to achieve comprehensive evaluation and accurate interpretation to better guide learning and teaching.

Fourthly, in the domain of teacher research, the competence of raising question with the highest weight (41%) is four times more than the competence of presenting research result with the lowest weight (10%) (Table 6). Similarly, the weight of collecting data is almost as low as the weight of presenting research results, only 11%. This demonstrates that science teachers are more concerned with practical issues in the process of conducting pedagogical research, rather than collecting data or publishing research results. Such results are not very consistent with the results of many existing studies in the world. For example, in Castle's (2006) qualitative study, a first-grade teacher and a fourth-grade teacher both pointed out that they will actively write and publish pedagogical research papers, and they will be very happy to share and exchange their research results in teacher professional development projects. Dobber, Akkerman, Verloop and Vermunt (2012) emphasized the importance of collecting data and analyzing research results and incorporated the above-mentioned competences into the training practice of professional development of pre-service teacher pedagogical research. Teacher research means that teachers use existing knowledge and theories to guide their own teaching practice, and teachers can improve pedagogical design, teaching implementation and leaning evaluation through their study of teaching practice. The concept of *teacher as researcher* has become a professional terminology in the field of education, just as *teacher as practitioner* has been widely used in the past decade or so (Stenhouse, 1981; Moynihan et al., 2015).

Conclusions and Limitations

Compared with the science learning research that has been continuously published in journals in recent years, there are few reports on the science teachers in China. In this study, four domains and 21 core competences of science teaching practice were identified and verified based on the consensus among experts. Specially, the level-one domains mainly include *Pedagogical Design*, *Teaching Implementation*, *Learning Evaluation* and *Teacher Research*, and their corresponding 21 core competences not only passed the fuzzy Delphi convergence test, but obtained a high consensus of the expert community, indicating that the core competences have high validity. The



results of this research are of great value to science teacher education and their professional development. Firstly, the competence indicators constructed by this research have a good reliability and can be used to evaluate and diagnose the competence performance of secondary science teachers. Secondly, these competency indicators can provide reference and enlightenment for the construction of the core competencies system and standards of science teachers in middle schools in China. In the future, there is still a lot of work worth doing. For example, teachers' knowledge (e.g., PCK, subject matter), dispositions (motivation, interest) should have been integrated into *teacher competence* system which is not the focus of this study. Moreover, this study will further introduce multidimensional item-response-theory (MIRT) to model several latent traits simultaneously and thus provide a promising approach to science teacher competence assessments.

Science teachers play a key role in successfully implementing science education reforms and providing all students with meaningful science learning opportunities. The construction of science teachers' core teaching competencies is the key step to promote the development of students' key competences. In order to ensure the content validity of the constructed competency indicators, this study constructed a community of experts, but this still cannot avoid a one-sided understanding of the core competencies of science teachers. Since researchers lack the experience of the real environment of professional learning and training during teachers' development and teaching practice, the description of individual characteristics of science teachers, such as their professional experience and competencies, are more based on literature research. In addition, due to the lack of professional standards and specialized documents for science teachers in China, many of the contents in this study draw more on science teacher competency documents published by countries /organizations such as the United States, Australia, and the European Union. Therefore, this research calls for the publication of the Chinese version of professional standards for science teachers as soon as possible to guide the professional development of science teachers.

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Declaration of Interest

Authors declare no competing interest.

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