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An Exploratory Study of Teacher Development in the Implementation of Integrated Science Curriculum

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Abstract

This paper reports an empirical study of teacher development in the process of implementing an integrated science curriculum in a junior high school in China. Six science teachers with different subject backgrounds were invited to participate in this study. A pragmatic model of teacher learning that includes both cognitive and situated-learning perspectives was adopted with a focus on the professional, social and personal aspects of science teacher development. The data were collected from multiple sources, including in-depth interviews, direct classroom observations and participation in science teachers' regular working meetings. The data analysis shows that the participants experienced various changes in the following aspects during the implementation of the integrated science curriculum: (1) updating science content knowledge; (2) reshaping the conception of science teaching; (3) establishing relationship with students; and (4) enhancing collegial interactions. The last part of this paper discusses these finding in the context of the literature on integrated science curricula and science teacher development.

Keywords Integrated science · Teacher learning · Teacher development · Implementation of science curriculum

Introduction

For a long time, the idea of an integrated curriculum has been advocated to provide more meaningful learning experiences that enhance the conceptual understanding and application of knowledge (Harrell 2010). The literature is filled with a multitude of forms of and justifications for this kind of curriculum (Blum 1991; Crane 1991; Harrell 2010; Venville et al. 2002; Wei 2015). Moreover, considerable research has been conducted to examine the implementation of the integrated science curriculum, suggesting that various issues and problems have been encountered in practice (Crane 1991; Nordine et al. 2011; Sun et al. 2014).

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Specifically, the persistence of traditional patterns of assessment, parental pressure for traditional academic standards, subject-based qualification, restricted instructional periods, insufficient teaching materials, unqualified teachers and the lack of school collaboration were found to negatively affect the implementation of integrated science. In the classroom, the integrated science curriculum has not been implemented as effectively as originally expected. This is demonstrated by the empirical study conducted by Sun et al. (2014) on the teaching of integrated science in China, which has shown that science teachers dominated communication with students, that integrative content was marginalised and that teachers were insufficiently competent in terms of the design and delivery of content for the areas of science, technology and society. However, scholars have paid little attention to the issue of science teacher development in the implementation of the integrated science curriculum.

It is commonly recognised that teachers are the most influential factor in the process of curriculum reform and that any kind of curriculum reform is prone to failure without their effective involvement. To enhance the chances of a successful innovation, teacher education programs, both pre-service and in-service, have often been connected with curriculum reform efforts. Since the 1950s, as described by Anderson and Mitchener (1994), "a large portion of science teacher education has been connected in some way to attempts to introduce curricular change" (p. 36). Consequently, teacher development has become an important topic of curriculum reform (Fullan 1993). In most cases, such reform calls for radical changes in teachers' knowledge and beliefs about the subject matter along with changes in teaching and learning (van Driel et al. 2001). Therefore, the implementation of reforms can be seen as essentially a matter of teacher learning (Ball and Cohen 1999). In particular, this issue has become critical for the implementation of the integrated science curriculum because no reform has more influence on teachers than changing the curriculum (Venville et al. 2002). Moreover, compared with other kinds of curriculum innovations, the integrated science curriculum reflects the vision and ideas of contemporary curriculum reforms and instructional innovation (see National Research Council (NRC) 1996, 2012), which include a consideration of social relevance, links to students' daily lives, the integrated knowledge of different scientific disciplines and cooperative learning. Based on these discussions, the researcher argues that the integrated science curriculum provides a special context for science teacher learning and development. This topic merits further exploration.

In China, the integrated science curriculum has been attempted for several decades at the junior secondary school level and was widely promoted across the country as part of recent curriculum reforms (Ministry of Education (MoE) 2001, 2011). As a response to the international tendency of science curriculum reform, the integrated science curriculum is recognised as integrating four traditional subjects (biology, chemistry, geography[1] and physics) into a new course in junior high school with the purpose of solving the long-term problem of students' overburdening schoolwork and encouraging student initiative (Wei 2009). In the national standards of science curriculum (grades 7–9), scientific literacy is defined as the goal of science teaching and learning and the curriculum content is composed of five domains: (1) scientific inquiry; (2) life sciences; (3) physical sciences; (4) earth, universe and space sciences; and (5) science, technology, society and environment (Ministry of Education

[1] In China, In China, for a long time, geography has been offered as a separate subject in the stage of junior high school, including natural geography and human geography in terms of its subject matter knowledge. When the integrated science was initiated, the part of natural geography (roughly equivalent to the Earth and Space Science) was incorporated into the new curriculum. And most of geography teachers have been involved in teaching the new integrated science at school level.

(MoE) 2001). To promote this reform, the educational administrations of all levels, from the central authorities to local governments, have dedicated considerable manpower and material resources, while cultivating favourable public opinion (Sun et al. 2014). Due to these characteristics, it is reasonable to assume that this curriculum reform poses a great challenge to in-service science teachers while providing a good opportunity for professional development. Based on this premise, this study aimed to explore the development of in-service science teachers with different subject backgrounds in the context of implementing the integrated science curriculum (grades 7–9) in China.

Professional Development and Teacher Learning

Professional development is an essential part of improving the quality of teaching in schools (Bolam 2000; Hargreaves 1994) and has always been accompanied by curriculum innovation and educational reform with the intention of helping teachers realise these improvements in their classrooms. Hence, a variety of approaches to teacher professional development have been suggested in the literature, such as professional development workshops, conceptual change strategies, problem-based learning, case methods, self-study, action research and collaborative learning communities (Wallace and Loughran 2012). To avoid the "conceptual vagueness" (Coffield 2000, p. 3) of the term "professional development", educational researchers have advanced the concept of teacher learning to refer to "the process of acquiring new ideas, changing or deleting old ones, and gleaning new knowledge and skills" (Davis 2001, p. 5). Here, *professional development* has a broader and more general meaning while *teacher learning* has a more specific and individual meaning. Franser et al. (2007) deliberately distinguished between the two ideas: *teacher learning* "can be taken to represent the process that, whether intuitive or deliberate, individual or social, result in specific changes in professional knowledge, skills, and attitudes, beliefs or actions of teachers" (p. 156–157) while teachers' *professional development* often "refers to the broad changes that may take place over a longer period of time resulting in qualitative shifts in aspects of teachers' professionalism" (p. 157). As for science teachers, Luft and Hewson (2014) argued that the specific character of science should be "an essential ingredient" of teacher learning (p. 889). That is to say, science teacher learning cannot occur without *science* itself. In this sense, the change of the school science curriculum from being subject-based to being integrated constitutes an essential ingredient of science teacher learning.

In the literature, teacher learning is conceptualised from the perspectives of both cognitive theory and situated-learning theory. For example, Hoban (2002) analysed teacher learning by taking into account individual processes and social and contextual influences. In a similar vein, Borko (2004) argued for placing emphasis on both the individual teacher (the learner) and the wider social systems in which they participate. For teachers, the author emphasised that learning takes place in a variety of aspects of practice, "Including their classrooms, their school communities, and professional development courses or workshops. It can occur in a brief hallway conversation with a colleague, or after school when counseling a troubled child" (Borko 2004, p. 4). Wallace and Loughran (2012) placed these two perspectives onto two ends of a continuum and argued for a pragmatic position of teacher learning that incorporates both theoretical positions. According to them, this pragmatic position recognises that:

> Teachers operate as individuals, making choices about levels of engagement, processing information and reflecting and acting on that information. Also, teachers' learning is inextricably linked to the learning of others – to students' learning, colleagues' learning and organizational learning (p. 303).

In a specific sense, Simon and Campbell (2012) conceptualised teacher learning as a combination of growth of the teacher's knowledge, teaching practice in a particular setting and social interactions with others. These ideas point to an earlier book entitled *Teacher Development: A Model from Science Education* (Bell and Gilbert 1996). In this book, Bell and Gilbert (1996) proposed a model of science teacher development on the basis of a 3-year study focusing on the changes in a group of science teachers when implementing new approaches in New Zealand. What makes this model relevant is that it portrays teacher development as taking place in three domains: professional ("developing ideas and actions"), social ("developing collaborative ways of relating to other teachers") and personal ("attending to feelings") (Bell and Gilbert 1996, p. 485). According to Bell (1998), these three domains are interactive, independent and "development in one aspect cannot proceed unless the other aspects develop also" (p. 682). Moreover, Bell and Gilbert (1996) identified how progress occurs in each of these domains. For example, teachers might experience the three stages in the professional domain, "trying out new activities", developing "ideas and classroom practice", and "initiating other development activities" (p. 485). Based on this framework, this study addresses the following research question:

> What, if any, are the changes of science teachers in the professional, personal and social aspects of teacher development during the implementation of an integrated science curriculum in a junior high school in China?

Methods

Context and Participants

Wayue (an alias) is a public junior high school (grades 7–9) in a coastal city in southern China, and the school is typical in terms of its enrolment of students and social reputation. With almost 50 years of history, Wayue enrolled 786 students in 18 classes and recruited 72 staff in the academic year when this study was conducted. Out of all teachers, there were ten science teachers who were divided into their subject backgrounds: three in physics, two in chemistry, three in biology and two in geography. For several decades and up until the reform, Wayue had been offering separate science subjects in three grades: Biology in grade 7, Geography in grade 8, Physics in grades 8 and 9 and Chemistry in grade 9, which is a common sequence in China (Wei 2009). Supported by the municipal educational authorities, since the autumn of 2013, Wayue has attempted to offer the course *Integrated Science* in grade 7, and 2 years later, this new curriculum was fully implemented across all three grades in this school. This study was conducted in the second academic year of implementing the integrated science curriculum in Wayue. Six of the science teachers were invited to participate in this study on a voluntary basis. All of them taught integrated science in the grade 7 or 8 or in both grades during the period of this study. Four of them had a year of experience teaching integrated science when this study began. The demographic information of these six science teachers is listed in Table 1.

Data Collection

To understand teacher learning and development, as suggested by Borko (2004), “we must study it within these multiple contexts, taking into account both the individual teacher-learners and the social systems in which they are participants” (p. 4). Specifically, as described earlier, science teacher development generally comprises three intertwined domains: professional development, social development and personal development (Bell 1998; Bell and Gilbert 1996). To collect rich data relevant to the issue of teacher learning and development, an extensive fieldwork was conducted at Wayue from September 2014 to May 2015, the second academic year of implementing the integrated science curriculum, with the actual duration of 7 months (deducting 2 months for the winter vacation). The data were mainly collected from three sources: interviews, direct classroom observation and observation of teachers’ meetings, with interviews being the primary data source. A semi-structured interview was conducted with each of the participants with a focus on their initial feelings and impressions of integrated science, the difficulties and problems they encountered when they began to teach integrated science, the achievements of enacting integrated science and their current feelings and impressions of the integrated science curriculum. The interviews were often conducted in the meeting room at Wayue between the researcher and one teacher. Generally, the interview started with a discussion of the teacher’s life and working experience, and then gradually shifted attention to their experience of teaching integrated science. During the interview, the researcher paid great attention to the specific incidents and vignettes mentioned by the participants that occurred in the process of their teaching integrated science. For each participant, the first formal interview lasted approximately 40 to 60 min. All of the participants were interviewed more than once. The subsequent interviews were mainly used to clarify the meaning and probe the details of the aforementioned situations and vignettes. With the permission of the interviewees, all of the interviews were recorded, and all verbal content pertaining to the research question was subsequently transcribed for data analysis. The participants’ science classes were observed by the researcher with a range of two to five classes for each participant during the period under study. Moreover, the researcher participated three times in the ‘collective lesson preparation’ meeting at Wayue, which was regularly held to exchange ideas among science teachers

Table 1 Demographic information of the participants

Participants	Teaching grade	Subject backgrounds	Years of teaching
Ms Wang	7th	Physics	10
Ms Huang	7th, 8th	Geography	18
Mr Zhao	8th	Chemistry	20
Mr Luo	8th	Physics	22
Ms Hong	8th	Biology	8
Ms Liu	7th	Biology	4

who were teaching the same grade. As a participant observer, the researcher was concerned about the issue of teacher development and teacher learning embodied in the interaction among the participant science teachers. The interview transcriptions, together with field notes taken in class observations and participation at the meetings, constitute the raw material for data analysis.

Data Analysis

In contrast to a theory-driven approach, grounded theory provides an approach for investigating previously unreported areas (Creswell 2013). The strategy of grounded theory was adopted in this study for data analysis in that no reported study can be used as a referent in investigating the issue of science teacher learning and development in the context of implementing an integrated science curriculum. The data collection and analysis were initially carried out concurrently, and the data collection did not stop until saturation was reached (Strauss and Corbin 1998). The inductive analyses procedures were followed to generate detailed and meaningful codes and categories emerging from the interviews and field notes about teacher learning and development in the process of implementing the integrated science curriculum at Wayue. Coding and categorising was performed with the data collected from the interviews, while the field notes of the participant and non-participant observations provided the *context* of the categorisation (Maxwell 2013). As the focus of this study is the professional, social and personal development of science teachers, the literature on science teacher learning and development was also taken into account when encoding. In essence, in terms of strategy, this study adopted a constructivist-grounded theory (Charmaz 2006).

The data analysis generally took place in three stages. In the first stage, data analysis was conducted for each participant. The line-by-line analysis was used to identify, sort and aggregate the segments of raw data into open codes, such as limited knowledge reserve, independent study, the combination of theory and practice, students' enthusiasm for learning and emotional exchanges among science colleagues. In the second stage, categorisation was conducted across the six participants at the level of focal codes with the purpose of capturing participant teachers' shared experiences of implementing the integrated science curriculum at Wayue. In this stage, open codes were progressively grouped in more inclusive categories (the change of science teaching conceptions, further study on science content knowledge, relationship with students and interaction with colleagues). The third stage focused on rechecking the specific evidence that supported those categories, reviewing the categories and the evidence iteratively and refining the categories until saturation was achieved. At this stage, two experts on science teaching and teacher education were invited to check and retrieve the supporting evidence and comment on the appropriateness of the coding and categorisation to ensure this study's validity and reliability. Over the iterative process of comparing, merging and selecting the focal codes identified in the first stage, four theoretical categories finally refined and renamed as follows: (1) updating science content knowledge, (2) reshaping the conception of science teaching, (3) establishing relationship with students and (4) enhancing collegial interaction. The data analysis scheme is presented in Table 2. The meanings of these four categories are explicated in the next section.

Table 2 Data analysis scheme

Categories	Open codes	Examples of evidence
Updating science content knowledge	• Limited knowledge reserve except in their own subject fields. • Independent study • Understanding of science concepts as continuing education and lifelong learning.	'Watching map' (Luo). 'Access content knowledge in various ways' (Huang) 'If you want to share a bowl of water with each of your students, you are supposed to own a pail of water' (Liu).
Reshaping conception of science teaching	• The combination of theory and practice. • Across boundary among various science subjects • Teaching assessment focus on students' real lives instead of textbook knowledge.	'I have recognised that when learning science individuals should be able to apply it' (Zhao). The vignette of teaching the topic of water cycle (Huang). 'What we need right now are those having something connected with students' daily lives' (Luo).
Establishing relationship with students	• Students' enthusiasm for learning influenced teachers' emotions. • Respectfulness received from students. • Students' resistance toward teachers gradually reduced.	'I was indeed impressed by the students' strong thirst for knowledge' (Luo). 'When some colleagues had a computer breakdown, their students suggested that they ask a science teacher for help' (Hong). 'In the past, students would get upset if I judged them, but now, they are all right with my negative comments or judgments' (Zhao).
Enhancing collegial interactions	• Learning from each other with regard to science content knowledge. • Emotional exchanges among science colleagues. • Creating an empathy among colleagues with different science subject backgrounds.	'Through the collective lesson preparation, I feel the collective strength of the group' (Huang). 'The discussion among colleagues is not only a matter of collision between different ideas and concepts but also gives us an opportunity for reflection and inspiration' (Wang). 'Even I do not know the answers of some of the questions you (the physics teacher) set for the students' (Huang).

Findings

Updating Science Content Knowledge

The implementation of the integrated science curriculum requires every teacher to teach the content of all science subjects including content beyond their own area of expertise. As a result, science teachers encountered the issue of updating their knowledge structure when they started teaching the integrated science curriculum. In this study, almost all of the science teachers at Wayue initially struggled with handling multiple-subject content, having found themselves with a fairly limited knowledge of the content beyond their own subject fields. Mr. Luo, with a physics background, may be used as an example. As he stated, when he first began teaching integrated science, his knowledge structure of the sciences was as follows:

> Geography seemed to exist as a blank from my primary school to my university because I had never been attentive in any geography class. Whenever I look at a map there was always be the idea in my mind that 'the left side stands for the West, and the right side stands for the East' (laugh). As for biology, in my memory, it was one of the subjects included as a small portion of my college entrance examination. What I had learned was

> merely adequate for handling the examination. Once I got into university, I took no more classes related to biology.

Other participants expressed similar worries at the initial stage of teaching integrated science. A former geography teacher, Ms. Huang, gave the following comment in an interview:

> I am familiar with my own professional knowledge (geography), but I know almost nothing about the other three subjects. As you know, not being familiar with the subject matter makes it difficult to grasp its concepts and principles, not to mention the fact that I studied liberal arts in high school.

Mr. Wang, who had been teaching physics for 20 years, shared his inner thoughts at his first impression of the integrated science curriculum in an interview:

> For me, due to personal reasons, I barely learned any geography and biology in high school. Indeed, I had some knowledge of chemistry but most of this has since been forgotten. The gap between my knowledge and the upcoming teaching work placed pressure on me, and it represented an unprecedented challenge. Faced with this reality, we must become modest learners and keep pace with the times.

As for how to bridge the *gap*, Mr. Wang suggested that there were various ways to access scientific content in the information age, as long as one was determined to learn. Meanwhile, he added, what one might not be good at may also be improved upon by consulting colleagues with greater proficiency. At Wayue, many science teachers mentioned that the major approach that science teachers adopted for further study was independent study, which ranged from reading college textbooks to sharing ideas among colleagues to searching for material on the Internet. In regard to specific strategies, Ms. Huang shared her experience with the researcher, citing the importance of 'setting a general frame (of the relevant subjects) in your brain, then figuring something out when you need it'. Other teachers considered that it was also possible to learn from teaching on the basis of one's reserve of knowledge. As such, after a year or more of teaching, most of the teachers believed that in terms of subject content knowledge, there was nothing to be afraid of, and that any obstacle was surmountable.

The process of updating content knowledge enhanced the science teachers' understanding of such concepts as continuing education and lifelong learning. For instance, Ms. Liu, a former biology teacher, offered the following comments:

> As a teacher, let's say if you want to share a bowl of water with each of your students, the premise is that you are supposed to own a pail of water. I'm realising that my existing knowledge is far from adequate, and that I need to engage in lifelong learning. That's why the reeducation of teachers makes sense to me, and it can also be a process that stimulates my own continuing learning.

Additionally, teachers' desire to explore new knowledge was also encouraged during the process of updating the content knowledge of science. When it came to the experience of learning geography, Mr. Luo stated the following:

> A lunar eclipse occurs in the course of the planets' movements, then the ancients marked the dates by observing the changing phases of the moon. See, how brilliant they were! That was really interesting!

Another motivation that drove science teachers to learn science content knowledge stemmed from their awareness of its value. As Mr. Luo commented, ‘knowledge is acquired by myself, it thus belongs to me. Keep learning for this reason, if for no other: at least I can teach my child’.

Reshaping the Conception of Science Teaching

The primary purpose of an integrated science curriculum is to cultivate students’ scientific literacy (Ministry of Education (MoE) 2001, 2011) and not simply to prepare students for further study. As shown, the participants involved in this study enhanced their understanding of this objective over the period of teaching integrated science. As a former biology teacher, Ms. Hong stated the following: ‘Why are students learning science? To enable them to understand what is happening in this world, and to make judgments in a scientific way without being either scared or trusting blindly’. Compared with the traditional subject-based science curriculum, integrated science attaches greater importance to students’ application of scientific knowledge in their daily lives, which is an objective acknowledged by almost all of the science teachers at Wayue. When commenting on the issue of combining theory with practice, Mr. Zhao, with a chemistry background, made the following statement:

> Previously, we knew that attention should be paid to the combination of theory with practice in chemistry teaching, yet it turns out to be just an idea in teaching practice. Currently, I recognise that when learning science individuals should be able to apply it. This is what I understand about the integrated science curriculum.

Moreover, from the science teachers’ point of view, one noticeable advantage of the integrated science curriculum is crossing the boundaries among different subjects. In terms of crossing the boundaries, Ms. Huang, with a geography background, offered two explanations for the researcher. Firstly, for the students’ sake, integrated science may help students to better understand various scientific concepts. Taking some teachers’ experiences as an example, when teachers explain the concepts of suspension, emulsion and solution, the concept of density in physics may help students to distinguish among these three concepts. Secondly, for the teachers’ sake, integrated science enables the effective blending of content knowledge from different subjects. Ms. Huang provided an example of the former and current methods of teaching the topic of the water cycles:

> In the past, my horizon was defined by the field of geography. However, the situation changed after combining the content knowledge of physics and chemistry. Previously, I taught the water cycle in the traditional way, the major points of general circulation, the ocean’s circulation and the inter-land circulation, and that’s it. But now, when I teach the same topic, I add supplementary knowledge about physics and biology, such as knowledge about the three states of water and transpiration.

Influenced by traditional assessments and evaluations, the science teachers showed an inclination to use certain questions for worksheets and exams. Interestingly, changes in the science teachers’ emphasis may be witnessed in their choices of questions. According to most of the teachers, it was easy to find the answers to the traditional exam-oriented questions, but these questions were unsuitable for use in integrated science. This explains Mr. Luo’s statement:

> Those traditional questions are subject-based and theoretically oriented, which are disconnected with the present teaching practice in integrated science, so they are unusable. What we need right now are items having more of a connection with students' daily lives.

Inspired by questions proposed or discussed by students, the science teachers at Wayue drew up worksheets and examination questions by themselves. In their words, they were 'creating questions for students' practical concerns. Mr. Zhao, a former chemistry teacher, offered the following comment:

> Previously, creating questions was more like setting 'traps' for students, one 'trap' after another, for tricking their judgment. And now, teachers are actually turning these 'traps' into questions based on students' real lives.

In terms of the teaching assessment, the science teachers still paid considerable attention to the degree of students' mastery of the subject material. Almost all of the participants in this study expressed the same idea in interviews: that their teaching effectiveness was largely evaluated by their students' exam results. Hence, when the teachers talked about their teaching methods, they believed that although the inflexible training by stuffing exercises was not to be adopted when teaching integrated science, appropriate exercises were still necessary for students to obtain satisfactory exam results. Even so, subtle changes could be observed in the teachers' conceptions of teaching assessments to include a focus on the real lives of students instead of on textbook knowledge. In the previous chemistry classes, teachers explained the concept of combustion and emphasised the step of removing at least one condition of combustion to put out a fire, as highlighted in the textbooks. When teaching the same topic in the integrated science class, Ms. Hong, a former biology teacher, provided a question for students to discuss: What will you do if your house is on fire? Students came up with different solutions while one student answered seriously, "I will run out to the street!" Ms. Hong responded quickly and positively, "Great! That's one of the options." Ms. Hong reflected on this teaching vignette in an interview:

> In previous classes, the student would be criticised because his answer seemed weird and irrelevant. But now, I thought I should give him a positive comment. In real life, as you know, once the fire grows stronger, the only thing one should do is to stay away from the danger.

Establishing Relationship with Students

An animated climate was observed in science classrooms at Wayue, where students showed great interest in learning integrated science. Moreover, the students' enthusiasm greatly and positively influenced the teachers' emotions, which can be illustrated by following examples. Ms. Huang, a former geography teacher, mentioned one teaching vignette during the interview. In one class session, which focused on the 'chemical changes', she put a question to a student: How do you distinguish between baking soda and salt using materials from your home? She initially thought that the student's responses should be "use vinegar to make a judgment." Surprisingly, she received various kinds of answers from the students, for example, some students suggested that the two condiments should be tasted in the mouth for the condiments are non-toxic and salt should be salty. There were many other creative answers. One student wrote: "I took morning glory from my home to make juice, made it an alkaline indicator, baking soda is an alkaline substance, and salt is a neutral substance, thus leading to the distinction." At that moment, the teacher fully sensed the students' enthusiasm and potential for learning. She could not help make this comment when talking with the researcher:

> It was definitely an eye-opening experience for me! I had not been in a situation like that in any of my previous geography classes. But now, you know, teaching integrated science, you can expect anything from the students. The students' answers prompted me to believe that the direction of curriculum reform is correct. As I see it, integrated science has changed students' singular way of thinking and widened their vision. Similarly, I've changed my conception of teaching, that is, I now think the student's answer is okay as long as it makes sense, without necessarily being in accordance with the so-called standardised answer.

Mr. Luo shared a teaching vignette from a class session in Grade 7 that focused on the topic of the classification of organisms. Students were asked to list animals and plants that they observed in their daily lives, and were expected to report on the kinds of criteria they had adopted to classify them as animals or plants. Some students set the criteria as "if one was able to eat," others tended to decide with "if one was able to walk." Whenever a student came up with one particular criterion, there was another student objecting with counterexamples, leading to a highly animated class climate. Some students did not even wait to say something while the teacher was interacting with the more introverted students, "Sir! I have another idea!" they kept shouting. When recalling this moment, the teacher said to the researcher, "I was indeed impressed by students' strong thirst for knowledge, which I had not previously seen in my geography class." After a short silence, Mr. Luo added, "we won't have any regrets regarding the students if we teachers remain dedicated to teaching."

Nearly all of the interviewed science teachers mentioned a questionnaire survey that was conducted in Wayue on the students' favourite teachers. The survey results revealed that the top five of the students' favourite teachers were almost all science teachers. When we asked the teachers how they felt when they learned about this result, their responses were almost the same, "Very happy!", "So glad to know!" Regardless of the results of the statistical index of that survey, it was obvious that the survey greatly strengthened the science teachers' enthusiasm for teaching integrated science. Furthermore, what made them happy was the students' sense of sincerity and respectfulness. Ms. Hong proudly made the following comment:

> When some colleagues had a computer breakdown, their students suggested asking a science teacher for help. Students ask us everything, like 'is it good for health if there is blood flowing into one's mouth when one gets nosebleed?' Whenever they feel under the weather they come to the science teachers and try to find out why. We are kind of regarded as, you know, a 'living' encyclopaedia, sort of god-like (laugh).

Along with the implementation of the integrated science curriculum, the relationship between students and students was becoming closer, and student resistance to teachers was being gradually reduced. Mr. Zhao, a former chemistry teacher, stated, "In the past, students would get upset if I judged them, but now they are all right with my negative comments or judgments." The teacher provided an explanation by stating that "Students are kind of worshipping science teachers' erudition, so they do not really mind if you judge them." Additionally, owing to the implementation of the integrated science curriculum, science teachers are in charge of fewer classes, and hence they have more opportunities to know the students better.

New approaches such as collaborative learning and group learning were encouraged for science teachers at Wayue prior to the implementation of the integrated science curriculum. However, these approaches were not used in previous subject-based teaching practice due to the heavy teaching loads. As a biology teacher, Ms. Liu recalled, they often had to change classrooms without knowing individual students' actual levels of proficiency and thus were not be able to organise group learning. According to her, this situation changed after the implementation of the integrated science curriculum because science teachers had more time to interact with students. This teacher offered the following reflection when talking about group learning in her science class:

> Now, it is quite different. I know every student in my class. I can make adjustments if I notice a problem in any group. And if anyone is reluctant to take part in group study, I am able to immediately and accurately call a student's name. And I know which students require extra attention.

Enhancing Collegial Interactions

Prior to the curriculum initiative, biology, geography, chemistry and physics were taught in different grades at Wayue, and the science teachers with different subject backgrounds had little interaction with one another. With the implementation of integrated science, each teacher taught two or three classes, with each class having four sessions per week, and with each teacher responsible for content that was beyond his or her own scientific discipline. Under such circumstances, it became inevitable that colleagues would help one another. The interactions between colleagues with various science backgrounds occurred on several occasions. The first occasion is the collective lesson preparation. All of the science teachers previously acquired their science knowledge in the relevant departments of their teaching universities/colleges, and thus they were familiar with traditional subject content for junior high schools. With the implementation of the integrated science curriculum, however, science teachers recognised that they needed to learn from one another. Collective lesson preparation was an important approach adopted at Wayue to improve teachers' professional learning and development. Since the implementation of integrated science, collective lesson preparation has become a focal point for group learning. In most cases, this collaboration started with a science teacher with specialised content knowledge preparing a certain lesson plan in advance. Then, he or she became responsible for explaining this topic to other colleagues at the group meeting. Meanwhile, colleagues with different scientific backgrounds came up with ideas for teaching the relevant topics from a student's point of view. The researcher participated in a collective lesson preparation whose focus was on the topic of the Earth and the universe, and with Ms. Huang, a former geography teacher, being the main speaker. In accordance with the requirements of the curriculum standards and the textbook, she first talked about the phases of the Moon and the solar and lunar eclipses from the perspective of a geographer. Unfortunately, after her explanation, the other three colleagues became confused. One of them complained, "We have never learned this kind of knowledge before. We can hardly make sense of this information, not to mention students." Another teacher suggested, "It might be better if we present the content in an experiment." Finally, Ms. Huang decided to adopt this suggestion, using a relatively bright lamp as a light source in the classroom and asking each student to prepare two balls with different sizes representing the Earth and the Moon. Ms. Huang remembered this event as follows:

> Through the collective lesson preparation, I feel the collective strength of the group. In order to effectively teach integrated science, I feel that all members from the lesson preparation team must put their heads together and learn from others' strong points to offset their weaknesses. Lesson preparation cannot be achieved by individual strength alone.

The second occasion is the emotional exchanges among science teachers. As Ms. Huang, a former biology teacher, recalled, before the implementation of the integrated science curriculum, science teachers only occasionally listened to and interacted with one other. As she explained, this situation changed after the implementation of the integrated curriculum, and colleagues from different backgrounds began to prepare lessons, and observe and evaluate classes together, thus leading to some emotional exchanges and even to some conflict. An interesting vignette was provided by Ms. Liu, a former biology teacher. In an open class, when the topic of electrical conductivity was taught, she put a question to the students, "What kinds of substance can conduct electricity?" Some students answered, "Stones." But she was not sure whether this answer was right or not. So, she asked anxiously, "Have you ever tried?" Some students said "yes" while others said "no." Ms. Liu responded in anger, "You have no say in this matter if you've never tried it!" After the class, colleagues who observed this class commented that she should not have been so harsh and that it might discourage students in learning science. Ms. Liu was shocked by those critical comments, and said in an interview, "That was indeed an unforgettable lesson for me. Since then, I have been not been opinionated like that, instead, I started to encourage students try new things." When talking about the interaction among colleagues, Ms. Wang, a former physics teacher, concluded:

> The discussion among colleagues is not only a matter of collision between different ideas and concepts but also gives us an opportunity for reflection and inspiration. Also, discussion deepens mutual understanding and trust, which is beneficial for future cooperation.

The third occasion is the creation of empathy among teachers of different subjects. Traditionally, physics and chemistry played an important role in senior high school entrance examinations, and when subject-based teaching prevailed, physics and chemistry teachers used to pay much attention to the teaching of specific knowledge points. Influenced by traditional habits, when those teachers started teaching integrated science they often worried that the content knowledge they delivered to the students was inadequate. For example, in the previous physics curriculum, the concept of water destiny constituted a difficult and differentiated knowledge point, and physics teachers needed much time to teach this part of the curriculum. However, in the new science textbook, the same content knowledge contains merely three sections and teachers are advised to teach that material within 2 weeks. Handling such difficult and differentiated knowledge within such a short time created some concern among the physics teachers. However, teachers with other specialised backgrounds considered this situation from a different perspective. In a meeting of the collective lesson preparation, while looking at a test paper prepared by a physics teacher, Ms. Huang, a former biology teacher, complained by saying that "Even I don't know the answers to some of the questions you (the physics teacher) pose for students." This complaint became a sore spot for the physics teacher and other colleagues. They were reminded that the previous standards seemed to be too difficult, even for science teachers with other backgrounds. Moreover, they thought that integrated science should not simply follow the previous method of teaching and that instead the teaching requirements should accord with students' actual receptivity.

Discussion

Based on the framework proposed by Bell and Gilbert (1996), this study investigated the learning and development processes of science teachers with various backgrounds during the implementation of the integrated science curriculum in a school setting at Wayue, a typical junior high school in southern China. By adopting a grounded theory approach, four categories were identified with the data gleaned from multiple sources, they are (1) updating science content knowledge, (2) reshaping the conception of science teaching, (3) establishing relationship with students and (4) enhancing collegial interactions. With reference to the professional, personal and social domains in Bell and Gilbert's (1996) framework, the first category is mainly associated with the professional domain, the second category corresponds to the personal domain and the third and fourth ones correspond to the social domain. As a whole, these four categories embody the development of science teachers and reflect the changes in teacher learning during the implementation of the integrated science curriculum. As indicated in this study, these categories are not in isolation but connected with one another. For instance, in order to update their content knowledge of science, science teachers need to communicate with colleagues, thus enhancing collegial interactions. While their close relationships with students are established, science teachers' conception of science teaching is under reconstruction. Moreover, this kind of interrelationship also exists between the implementation of integrated science and each of the four categories respectively: it is the implementation of integrated science that results in all of the four categories while science teachers' learning and development in these aspects promote the implementation of integrated science. The interrelationship among the implementation of integrated science and the four categories of science teachers' learning and development is shown in Fig. 1.

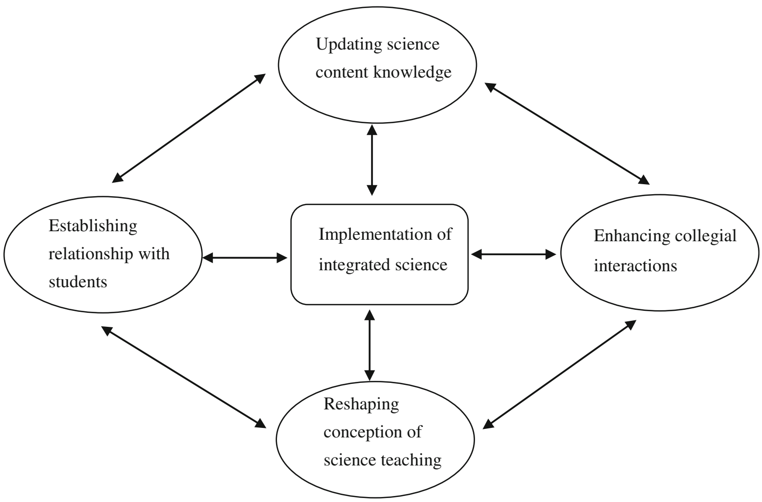

Fig. 1 The interrelationship between science teachers' learning and development and implementation of integrated science

The contributions of this study to the literature are manifested in a couple of ways. Firstly, it provides empirical evidence in support of the statement that science teacher development has really occurred in the process of implementing the integrated science curriculum. Secondly, as indicated in this study, the changes in science teachers' learning and development took place not only in the cognitive area but also in the emotional and social areas, demonstrating that a pragmatic perspective has been effective for investigating science teachers' learning and professional development (Simon and Campbell 2012; Wallace and Loughran 2012). More significantly, for the first time in the literature, this study has revealed the journey of science teacher learning and development in the context of implementing the integrated science curriculum, which are represented in the aforementioned four categories.

As mentioned earlier, many countries have encountered problems in the implementation of the integrated science curriculum and, especially, teacher content knowledge remains one of the most difficult challenges (Harrell 2010). In this study, it was found that science teachers at Wayue urgently needed to update their content knowledge to teach integrated science and this required the adoption of a variety of approaches. Moreover, most teachers displayed a gradual increase in their confidence regarding content knowledge in the discipline that was beyond the area of their own expertise. Another important factor that affects the implementation of the integrated science curriculum is science teachers' awareness of subject-based teaching and learning (Beane 2000; Venville et al. 2002). The above two factors are interrelated and are associated with teaching 'out-of-field', which can be seen as a boundary-crossing event (Hobbs 2013). According to Little (1993), a teacher affiliated with an academic subject area, especially at the secondary level, develops a loyalty to the subject matter, which then forms a component of the teacher's identity. Similarly, Rogers (2011) argued that 'immersion in the processes of learning and knowing, within a specific disciplinary context, (can have) a significant impact on students' emerging professional identities and on their values as teachers' (p. 249). Moreover, Hobbs (2012) argued that secondary school teachers usually have a historical engagement with a subject and discipline from school, university study, or the workplace, thus, they may bring some certain attitudes and preferences that have been established to this subject into the classroom. These discourses suggest that it is not easy for subject-based science teachers to transform their identity and become integrated science teachers. In this study, fortunately, it was found that with the implementation of integrated science, teachers gradually developed a greater understanding of the fundamental purpose of integrated science, attached importance to the connection between various disciplines and chose to teach and evaluate from the student's perspective rather than simply adhering to the demands of disciplines. Based on these findings, it can be referred that science teachers with various subject backgrounds would be willing and competent to teach the integrated science curriculum with their identity of science teachers reinterpreted. Obviously, it is the *boundary object* (Akkerman and Bakker 2011), the implementation of the integrated science curriculum in this study, that has provided opportunities for science teachers with various subject backgrounds to update their science knowledge, reshape their conceptions of science teaching and reinterpret their identity as science teachers as well (Avraamidou 2014; Beijaard et al. 2004).

The relationships between students and teachers and among colleagues demonstrated the social aspects of the development of science teachers in this study. Empirical studies have shown that students were improved in emotional and affective aspects in learning integrated science (Clark and Clark 1994; Ross and Hogaboam-Gray, 1998; Yoon et al. 2014) despite a controversy on students' gains in the cognitive aspect (Venville et al. 2002). This study found that students' interest in learning integrated science stimulated the enthusiasm of their teachers and further strengthened the relationship between teachers and students. Generally, the management and evaluation of teachers in a school is assigned to different academic departments. In normal circumstances, the distribution of benefits and the sharing of resources among departments remain stable and balanced (Goodson 1993). Nevertheless, the implementation of the integrated science curriculum tends to break with this continuity, leading to some tensions in interpersonal relationships. However, as shown in this study, science teachers with different subject backgrounds have come together to engage in positive interaction when recognising the complementarity of the content knowledge and the need to solve common problems in teaching.

As we know, science teacher learning and development never occurs in a vacuum. The four categories concerning science teacher learning and development reported in this study are embedded in social contexts, including various teacher development programs organised by the central and local educational administrations, the support provided by the educational authorities and public concern over curriculum reform in China (Ding 2015; Sun et al. 2014). In this study, science teacher learning and development were also associated with the management system and school culture of Wayue, which is enlightened and conducive to curriculum innovation. However, whether and how these factors promote the development of science teachers need further investigation. In addition, some questions regarding the mechanism of the development of science teachers require further exploration. For example, as shown in this study, teachers' confidence in teaching integrated science is on the increase. However, it is unclear whether this means that teachers can make sense of the content knowledge outside of their subject areas as thoroughly as that of their own subjects, thus eliminating the *language walls* between different subjects? Is the harmonious relationship between colleagues just a temporary phenomenon? Do the boundaries between different subject areas really disappear? Do science teachers with different subject backgrounds, such as physics, chemistry, biology and geography, have the same experiences and emotions regarding the implementation of science curriculums? The boundary crossing literature (such as Akkerman and Bakker 2011; Hobbs 2013) may be used as a theoretical framing to further explore the problems and issues in the implementation of the integrated science curriculum when science teachers move into teaching subjects they are not specialised in.

Lastly, it must be mentioned that this study mainly reports the positive changes in science teachers' learning and development with less attention on the related difficulties and dilemmas confused by participants when implementing the integrated science curriculum, which involve a wide range of issues and problems and cannot be fundamentally solved in a short period of time. In particular, external evaluation systems guided by test scores have restricted the empowerment of science teachers, thus creating a formidable bottleneck in the development of science teachers and in the implementation of an integrated science curriculum.

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