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Development of A Grade Eight Taiwanese Physical Science Teacher's Pedagogical Content Knowledge Development

HSIAO-LIN TUAN* AND RONG-CHEN KAOU**

**Graduate Institute of Science Education*
National Changhua University of Education
Changhua, Taiwan, R.O.C.
***Hsing-Shen Junior High School,*
Taidong, Taiwan, R.O.C.

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Abstract

The purposes of this study were to examine a beginning Taiwanese female science teacher's physical science teaching, and how her science teaching developed from her senior year to her first semester of classroom teaching. Both microscopic and macroscopic pedagogical content knowledge (PCK) were implemented in the investigation. A qualitative research method was applied. The research was conducted from Shu-May's senior year to the first semester of her beginning year. The findings revealed that the nature of Shu-May's PCK consisted of instructional strategies and representation. Her instructional strategies were characterized by the verification method of introducing science concepts. Her instructional representation included linguistic expressions, calculation problems, demonstration, daily-life experiences and relevant examples via verbal and visual display. Shu-May's PCK development revealed integration, relevance, and specificity features. Shu-May's knowledge of her students changed from a general view of student learning to a more specific understanding of their content learning ability. Her content knowledge also changed from a general view of the physical science discipline to specific knowledge of what students should know about each topic. Factors influencing Shu-May's PCK development were her perceptions of science teaching and students' science learning, her insensitivity in both judging students' level of understanding and deciding on appropriate goals for the lessons, her declining retention of pedagogical knowledge learned in teacher education programs, and the different cultural norms she perceived in different teaching contexts.

Key Words: pedagogical content knowledge, beginning science teachers, teacher's professional development, physical sciences, junior high schools

I. Introduction

Teachers play a key role in influencing students' science learning. Science teacher education also plays a crucial role in educating science teachers to be competent and capable of integrating content and pedagogical knowledge in classroom teaching. During the past decade, research on science teacher education has gained more attention than before. Reforms in science teacher education programs have progressed in many states in the U.S. (Brunkhorst, Brunkhorst, Yager, Apple, & Andrews, 1993; Gilbert, 1994; Tippins, Nichols, & Tobin, 1993).

In Taiwan, a decentralized teacher education system was approved by legislators; teacher education is now in a transition stage. Both normal universities and general universities can offer science teacher education programs. In normal universities, science teacher education programs are located within science departments. When students pass the entrance examinations and enroll in the science departments, they need to take both content and education courses together for four years; practice teaching in a junior high school requires an additional year. Therefore, students enrolled in normal university program take five years to become a teacher. In other general universities, students enrolled in a chemistry department need to take additional education courses offered by a teacher education program to become a teacher. Once they receive a diploma they need to find a high school in which to have a year-long practice teaching experience.

The new legislation in teacher education raises a lot of research issues, including developing an assessment system for evaluating science teachers and developing appropriate educational programs for science teacher education. Although there are many ways to improve science teacher education, Finley, Lawrenz, & Heller (1992) indicated that carefully examining the impact of science teacher education on beginning teachers' professional development was crucial in designing future teacher education programs.

Presumably, a teacher needs to have content knowledge and know how to teach in order to be a competent teacher. In other words, to be competent, teachers need to both possess and integrate content and pedagogy knowledge. However, few researchers have investigated the above assumption until the last decade. Science educators (Gess-Newsome & Lederman, 1993; Hashweh, 1987; Hoz, Tomer, & Tamir, 1990; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995) started to investigate the importance of both pre- and in-service science teachers' content and pedagogy knowledge and the way the knowledge was integrated in teachers' thinking and acting. Shulman's (1986, 1987) concept of PCK, which addressed the teachability of content knowledge, is another direction in investigating the integration of teachers' content and pedagogy knowledge.

Besides revealing the nature of how teachers' integrated content and pedagogy knowledge in thinking and acting influenced their teaching, teacher educators also expected to unravel the underlying process of teachers' professional development from the university through their field experiences. There are several models of teacher professional development including those of Fuller & Brown (1975), Berliner (1988), and Kagan (1992).

Fuller & Brown (1975) identified the process of a teacher's professional development from the survival stage to the impact stage. In other words, a teacher's concern passes from concerns about one's own adequacy to the teaching task and finally to his/her effect on students.

Applying both schema theory and cognitive science, Berliner(1988) constructed a five stage process of a teacher's professional development. It includes: novice, advanced beginner, competent, proficient, and expert stage. In the novice stage, a teacher's teaching performance is based on his/her rationale, which is inflexible and requires purposeful concentration. In the advanced beginning stage, a teacher learns strategic knowledge and becomes flexible in following rules in the classroom. In the competent stage, a teacher is able to choose a course of action, prioritize things and make plans. In the proficient stage, a teacher is able to pick up information from the classroom without conscious effort and is able to predict classroom events. In the expert stage, a teacher's performance is fluid and seemingly effortless. He or she uses standardized, automated routines in handling instructions and management. Berliner thought most beginning teachers were in the novice stage, and many second and third year teachers were in the advanced beginner stage.

Kagan (1992) categorized a teacher's professional development into five components: an increase in metacognition, an increase in knowledge about students, a shift in attention from self to students, development of standard procedures, and, finally, growth in problem solving ability. In Kagan's model, there was no specific indication that years of teaching experience were related to the developmental stages.

These authors provided some general ideas about how teachers may develop their teaching competence. However, they did not address how beginning teachers integrated what they had learned from content and pedagogy courses into their content teaching presentations, or how they develop their content teaching in the field, that is their PCK development. Future research needs to investigate specifically how beginning science teachers' develop their content teaching in a natural setting, and try to trace back the impact or lack of impact of science teacher education programs on their content teaching development. Only by this kind of examination can we know how to improve our future science teacher education in a more meaningful way for preservice science teachers.

Previous research on PCK includes: examining the nature and substance of teachers' PCK in mathematics and science teaching (Marks, 1990; Tuan, 1996a); investigating the knowledge beginning science teachers need to teach a particular science topic (Geddis, 1993; Geddis, Onslow, Beynon, & Oesch, 1993); exploring the development of pre-service science teachers' subject-matter knowledge, pedagogical knowledge, and PCK development (Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995; Tuan, 1996b); illustrating methods to facilitate science teachers' PCK (Barnette, 1991; Clermont, Krajcik, & Borko, 1993; Dana & Dana, 1996; Klienfeld, 1992; Ormrod & Cole, 1996); and comparing the differences of the PCK between novice and experienced science teachers (Clermont, Borko, & Krajcik, 1994; De Jong, 1997). The above studies used different definitions to describe PCK, thus influencing their research approach.

Tuan(1996c) reviewed research on PCK and concluded that research done on PCK revealed two views. The microscopic view has been emphasized by researchers like Shulman (1986, 1987), Kennedy (1990), McDiarmind, Ball, & Anderson (1989). These researchers have emphasized how teachers represent their understanding of a particular content topic to a particular classroom students' understanding level. The macroscopic view of PCK has been emphasized by research by Cochran, DeRuiter, & King (1993), who have treated PCK as the overlap of several domains of knowledge learned in the teacher education program, such as curriculum knowledge, pedagogical knowledge, subject matter knowledge, knowledge of students, and knowledge of context, and how these translated into thoughts and actions in classroom teaching. The more integration of the above domains of knowledge into the teachers' thoughts and actions in classroom teaching, the more their PCK developed. The difference between the microscopic and macroscopic views of PCK is that the former addresses a particular content topic while the latter addresses a broader base of content teaching across different topics. Tuan(1996c) also suggested that future studies done on this area should define the concept of PCK.

Researchers have reviewed a few studies on how pre-service/ beginning science teachers developed their PCK (Gess-Newsome & Lederman, 1993; Lederman, Gess-Newsome, & Latz, 1994; Lederman & Latz, 1995; Tuan, 1996b; Yang & Wu, 1996). These investigations either addressed the macroscopic view of PCK development (Gess-Newsome & Lederman, 1993; Lederman & Latz, 1995; Lederman, Gess-Newsome & Latz, 1994), or used the microscopic view to look at the PCK development of preservice teachers (Tuan, 1996a) or beginning biology teachers (Yang & Wu, 1996). None of the studies identified traced the development of a physical science teacher's PCK from one's senior year to the first year of teaching, or investigated the development of a teacher's macroscopic and microscopic view of PCK.

Based on the above reasons, the purposes of this study were to examine the characteristics of a beginning Taiwanese female science teacher's junior high school physical science teaching, how her science teaching developed naturally from her senior year to her first semester of classroom teaching, and examine the factors influencing the development of her PCK. Both microscopic and macroscopic levels of PCK were implemented in the investigation. Findings from this study should help science teacher educators not only gain more understanding about the nature of beginning science teachers' PCK, and how this knowledge changes during the first semester of teaching, but also help science teacher educators develop better science teacher education programs in the future.

II. Design and Procedure

1. Description of Science Teacher Education Program

This study was done in a normal university located in the middle of Taiwan. As mentioned before, preservice teachers enrolled in the chemistry department of the normal university have to take chemistry and education courses in the same department with the same classmates. Pedagogy courses offered in the chemistry department included foundations of education, secondary education, educational psychology, science education, instructional materials and chemistry teaching methods, and a practicum course. Courses that integrated content and pedagogy were chemistry teaching methods courses and practicum courses. After finishing their course work in the fourth year, preservice teachers have a year-long internship experience in a junior high school to practice teach, obtain a teaching certificate and receive a graduation diploma. Beginning teachers in their fifth year are graded and supervised by junior high school principals and college professors; however, in reality, they are doing the same work as professional teachers and seldom ask their supervisors for help.

2. Description of Instructional Materials and Teaching Methods Course and Practicum Course

The first author offered two courses for the chemistry department, a chemistry teaching methods course and a practicum course. In the chemistry teaching methods course, the first author covered teaching strategies, such as lab teaching, conceptual teaching, discrepant event teaching, the learning cycle and creative science teaching. The aims of the course were to increase the preservice teachers' appreciation and teaching repertoire of different science teaching strategies. Instructional methods used for this course included introducing new methods, demonstration, group discussion, role playing, group presentation, and whole class discussion. Basically, the author was a role model using the above strategies in the class and then conducted group discussions to help preservice teachers discuss what they thought of the teaching methods.

Practicum courses were offered for two semesters. For the first semester, preservice teachers practiced microteaching twice on the topic they had chosen; in the second semester, they had a one-month practicum in a junior high school. Instructional methods used in the practicum course mainly focused on reflective teaching (Schön, 1986). The author applied many methods such as journal writing, self analysis of one's own teaching and reflection on other classmates' suggestion to increase the preservice teachers' reflective ability on their teaching. The author also applied peer coaching to supplement their reflective teaching experience. Each preservice teacher was asked to choose their own peer coach. They then helped one another with lesson plans and gave feedback on each other's performance. After finishing each microteaching lesson, each preservice teacher needed to analyze one's own teaching, and also respond to the feedback from their classmates and peer coach. During their one month field experience, each preservice teacher needed to make a journal of their classroom teaching experience. After they came back from school, the author covered topics related to classroom management, science fairs, and teachers' professional development.

3. Context of the Junior high School

The junior high school where Shu-May taught was located in a rural county in central Taiwan, with farmers or blue-collar workers constituting the majority of the population. Thus, most of the students' parents did not have high expectations for their children's achievement. The learning environment in this school was more casual without the competitiveness of city schools. The class observed was an eighth grade physical science class of 45 "ordinary" students. An ordinary class in that school meant that the students' achievements were lower than the A class students. The school selected higher G.P.A. students from among the same grade level and put them into the A class in order to prepare them for passing the senior high school entrance examination. The other students were put into ordinary classes where probably none of the students would pass the senior high school entrance examination nor be able to enter public professional schools after their graduation.

4. Data Collection

Based on the nature of this study, a qualitative research method (Bogdan & Biklen, 1992) was applied. A beginning Taiwanese female science teacher, Shu-May, was involved in the study for many reasons: (1) she took the first author's chemistry teaching methods and practicum course in her senior year of college; (2) the researchers had collected teaching performance data in her senior year in the program; (3) the location of Shu-May's school was close to the university, enabling intensive classroom observation; (4) among her classmates, her G.P.A. was in the average range; and (5) she was willing to participate in the study.

A. Data Collection in the First Year

Data collection in Shu-May's senior year included two micro-teaching video-tapes of about 20 minutes each, one hour of real classroom teaching videotape, her lesson plans for the microteaching experience, and other assignments for chemistry teaching methods and practicum courses. These data were mainly collected by the first author, who was also her instructor for both the chemistry teaching methods and practicum courses. The second author had one year of junior high school teaching experience and two years of science education graduate courses. He was Shu-May's friend in college, played the role of an-observer-as-participant (Gold, 1958), and collected data on Shu-May's first year of teaching.

B. Data Collection in the Second Year

In the second year, data collection included a twice weekly classroom observation for one semester, interviews with Shu-May before and after her classroom teaching, and a collection of Shu-May's written documents such as her lesson plans, notes and students' tests. Formal interviews were conducted before, during, and at the end of the semester and addressed Shu-May's perceptions of junior high school physical science teaching, her chemistry knowledge and pedagogical knowledge (see appendix I). Informal interviews conducted before and after each classroom observation focused on Shu-May's plans for the topic she was going to teach, her knowledge of the topic she was teaching, the references she used in her teaching, and her reflection on her teaching. Researchers also interviewed Shu-May on the reactions collected from students. Document collection included her lesson plans, tests and students' test results during her first year of teaching.

5. Data Analysis

Data analysis was based upon the open-coding method (Bogdan & Biklen, 1992). The second author first analyzed all the interview transcripts and classroom observation field notes, and then generated an open coding system. The two researchers examined the raw data such as interview transcripts and videotapes of Shu-May's classroom teaching together in order to elaborate on the coding systems. The first author played a critical role in analyzing the raw data and reading the temporary findings written by the second author. She then evaluated these tentative results and suggested that the second author find more evidence to support or reject the findings until the authors reached a consensus. The peer debriefing procedure (Lincoln & Guba, 1985) was used in the data analysis to increase the trustworthiness of the findings.

Miles & Huberman (1994) suggested using tables to present qualitative findings, and a table was generated listing the frequency of Shu-May's teaching activities (Table 1). Together the researchers analyzed the beginning of three video tapes of Shu-May's teaching to count the frequency of her teaching strategies in order to gain consensus on the attribute and frequency of each teaching strategy. The second author analyzed the rest of the video-tapes of Shu-May's teaching performance. The definitions of each of her teaching activities are listed in Table 2.

The purpose of the study was to look at how the beginning teacher integrated content, pedagogy, and students together in thought and performance on her content teaching in a natural setting. Thus, teaching activities (Table 1, 2) were analyzed but the appropriate level of Shu-May's teaching performance was not. Another part of the data analysis that needs to be considered was that, based on the nature of the topics, each topic could accommodate different teaching approaches based on the content. For instance, an element and a compound can be introduced by using the history of science approach; for the water and air topic, the teacher could first use daily-life experiences for students to appreciate the importance of water and air, and then discuss the property of these matter. However, when we examined Shu-May's teaching, her teaching strategies were almost the same when covering different topics. Thus, we coded her teaching into different teaching activities (Table 2) and then examined how Shu-May organized these teaching activities, which were her teaching strategies, across topics. The third important issue that needs to be addressed is that during her fifth year Shu-May relied on her mental thinking when planning instead of actually writing down everything she needed to cover in the class. In addition, in responding to the authors, her thinking about teaching was to mention in general, some teaching tasks, such as lecture, demonstration, and problem solving. Thus, the authors could hardly analyze Shu-May's planning in terms of frequencies and level appropriateness of the representations listed in Table 1 & 2. Therefore, our data analysis relied on her verbal descriptions of teaching and actual observation of her classroom performance.

Lincoln & Guba (1985) listed four criteria for maintaining the trustworthiness of qualitative research findings. These are credibility, transferability, dependability, and confirmability. In this study, the two researchers knew Shu-May and had worked with her from her senior year to her first year of teaching. The second author stayed in the field for half a year, providing an opportunity for the researchers to collect Shu-May's PCK and to clarify the researchers' understanding. This prolonged engagement should help to increase the credibility of the findings. Triangulation methods (Bogdan & Biklen, 1992) were also applied in the data collection and analysis procedures, such as collecting data from different sources and including different researchers in the analysis of the findings. Finally, the study provided the following: detailed data analysis procedures, Shu-May's views of the research findings, comparisons between our findings and previous research, detailed information on the research context and the roles of the researchers. These methods were incorporated to increase the trustworthiness of the findings.

III. Findings

1. The Development of Shu-May's pedagogical content knowledge

A. The main organization of Shu-May's science teaching strategies did not change throughout the study; she used a verification method to teach science concepts listed in the textbook from the beginning to the end of the study. Toward the end of the study, Shu-May used more teaching strategies to help students memorize science concepts.

Analysis of Shu-May's teaching from her senior year to first year of teaching showed that her teaching activities(Table 1, 2) and ways of organizing these teaching activities were very similar to other preservice Taiwanese chemistry teachers (Tuan, 1996a). These teachers' content teaching were characterized as the verification way to teach science.

Shu-May had an opportunity to practice ideas introduced in the methods course in her microteaching experience during her senior year. However, she

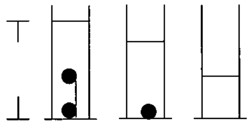
Table 1. Shu-May's Teaching Activities for Each Topic

Classroom Teaching Activity	Frequency						
	Topic Taught in Senior Year			Topics Taught in the First Half Year of Teaching			
	Microteaching Lessons		Field Experience Lessons	Measurement	Water	Influence	Elements
	Linear Movement in Velocity (27 min)*	Elements with Similar Properties (29 min)*	Property of Halogen (50 min)*	& Units of Metric (300 min)*	& Air (150 min)*	of Heat Matter (200 min)*	& Compounds (250 min)*
1. classroom management			1	32	17	12	17
2. review previous concepts	1	1	2	10	6	8	14
3. introduce formulas	2		1	5	4	4	5
4. ask for memorization			1	7	10	7	12
5. underlining important parts in textbooks and/or taking notes			2	12	13	16	21
6. emphasize the content which would be convered on test			1	9	3	5	6
7. using added scores to encourage Ss.				2			
8. ask open-ended questions	3	4	5	9	4	8	
9. ask individuals to respond	2	1		6	4		
10. provide opportunities for Ss to discuss	2	1		4	5		2
11. quiz					2	1	
12. explain science concepts	4	6	29	11	26	28	
13. summarize introduced concepts	3	8	17	4	20	15	
14. demonstrats problem solving	3			11	2	10	3
15. students do problem solving exercises	1			4	2		
16. provide daily life examples				34	17	20	2
17. use analogies to explain concepts	2	1		1	1	1	3
18. use illustration to explain concepts		4		1	16	7	10
19. use graps to facilitate problem solving	2			3	1	2	
20. demonstrate concepts using real objects	1	2	1	1	3	1	
21. demonstrate lab activities			1	2	3	1	1
22. Ss conduct lab activities		1	1	4			

* Length of teaching time.

thought the best way to present the velocity topic was a "traditional lecture." The strategies she used in introducing velocity were to introduce the key concepts at the beginning of the lesson, review the previous lessons in order to connect previous concepts to this topic, define velocity, provide problem solving techniques for both demonstrations and exercises for students to appreciate aspects of velocity, illustrate the difference between velocity and speed, derive a velocity formula, and summarize concepts. In her twenty-seven-minute microteaching experience, Shu-May's major emphasis was on ex-

Table 2. Example of Each Teaching Activity

Teaching Activities	Examples
1. Classroom management	T: Lin-Pin, do not talk in class, pay attention.
2. Review previous concepts	T: Last period we studied page 34, Density. Density = Mass /volume
3. Introduce formulas	T: Today I will introduce pressure, pressure = Direct force/area.
4. Ask Ss to memorize	T. The definition of the law of constant composition, the mass of all elements in a compound, has a certain ratio. This is very important, memorize it.
5 Ask Ss to underline important points or take notes	T: Look at page 161, the third line, the law of constant composition, all elements combine into compounds, their mass have the same ratio, this is very important, underline this paragraph.
6 Address the content which would be covered on test	T: "The law of constant composition is very important, it will be on the test."
7. Apply additional score to encourage students	T· If you answer this question correctly, I will add three points to your average score.
8 Ask open-ended questions	T· How to separate sugar and iron powder ?
9. Ask individual students to respond	T· Ah-Lin, density equals what divided by what?
10. provide opportunity for student discussion	After asking questions, Shu-May gave time for students to conduct discussion.
11. Quiz	After covering the content in the class, Shu-May asked the students to take out a piece of paper and pen to take a quiz. She then wrote down a question on the board: There is a fish tank on a square table. The table weights 1200g. The fish tank weighs 400g. Each side of the table is 10 cm in length. (1) What is the direct force? (2) What is the total contact area? (3) What is the pressure ?
12. Explain and introduce concepts from textbook	T: Let me introduce a term The vertical direction of the force on the object, we called the vertical force...How is the vertical force related to pressure? SS: Direct proportion
13. Summarize introduce lab finding and concepts	After explaining science concepts, Shu-May would summarize what she had just taught to the students on the blackboard. For instance, after introducing pressure, she then wrote down the following notes on the blackboard. P (pressure) = F (vertical force) gw kgw / A (area) cm^2 m^2
14. Demonstrate problem solving	T: look at page 45, there are two bricks How much does each brick weigh? SS: 2000g T: How about the length of the brick? (She wrote on the blackboard) SS· 20 cm T: How about the width of the brick ? SS: 10 cm T: How about the height of the brick ? SS. 5 cm. [Wrote the following notes on the blackboard] F=2000g Length 20 cm, width 10 cm, height 5cm T: Look at the brick lying on the table What is it's pressure on the table? Does it relate to vertical force divided by area? How much is the vertical force? SS: 2000g T: How much is area? SS:200 cm^2 T: Length times weight is 20 times 10 equals 200 [Wrote the following notes on the blackboard] $\frac{2000}{20\times10} = (10\ g\ /\ cm^2)$
15. Let students do problem solving exercise	Shu-may wrote problem on the blackboard and asked the students to do the problem solving exercise in the class.
16. Provide daily life examples	After introducing how heat influenced matter, Shu-May talked about how water at 4 °C influences the ecology T: How can fish live in a lake covered with ice on the surface ? T: Because at 4 °C, water has the largest density Thus, let's compare 4 °C water and ice. Which one is on the top; which one is at the bottom? SS: 4 °C, water is on the bottom. T: So even if the lake is covered with ice, underneath the ice is the 4°C water; thus, the fish can stay alive.
17.Use analogies to explain concepts	T: The diffusion rate of Hydrochloride and ammonium is like a fat guy and a skinny guy racing. Generally speaking, the skinny guy runs faster than the fat guy. It is the same with the diffusion rate of gas. The lighter gas diffuses faster than the heavier one.
18. Use illustration to explain concepts	T: Chemical reaction is the rearrangement of atoms, such as carbon and oxygen combusting into carbon dioxide. The solid dot represent carbon. The hollow dots represent oxygen. $C + O_2 \rightarrow CO_2$ ● ○○ ○●○
19. use graph to facilitate problem solving	When Shu-May asked ss how to measure the volume of Pine-Pong balls, she drew a graph on the board and explained to ss how to do it. 120ml 100ml 80ml 
20. Demonstrate concepts using real object	Shu-May used a bottle of water to show ss the relationship between the depth of water and pressure.
21. Demonstrate with lab activities	Shu-May demonstrated lab activities from the textbook
22 Students conduct lab activities	Shu-May invited students to help her conduct lab demonstrations , or she let students do lab work in groups.

plaining science concepts to the students, who were also her classmates.

In Shu-May's first half-year of junior high school teaching, she used a similar teaching pattern in organizing her lessons. The pattern followed a usual sequence: (1) introducing science terminology; (2) using natural phenomena to illustrate science terminology; (3) explaining the definition of science concepts, principles, and/or formulas; (4) providing examples to re-emphasize concepts, principles and/or formulas; (5) providing problem solving exercises to help students understand previous concepts; and (6) using quizzes to evaluate students' understanding. In general, Shu-May's teaching activities were mainly organized to focus on introducing science concepts to students, and to help students memorize the concepts in order to be successful in taking school examinations.

The literature of PCK has indicated (Geddis, 1993; Shulman, 1986) that using conceptual change teaching methods to overcome students' misconceptions is one important feature of PCK. This characteristic was not found in Shu-May's science teaching from her senior year to the first year of teaching. Shu-May's way of organizing instructional strategies throughout the study were characterized as using a verification method to organize science concepts for students. Shu-May did make some changes in her instructional strategies at the end of the study; these were: (1) increasing some representations to help students appreciate science concepts; (2) increasing the frequency of helping students to memorize science concepts, such as underlining the important concepts and focusing on the possibility of the concepts on tests; and (3) practicing problem solving techniques (Table 1). These strategies were to help students get good grades on school tests.

B. Although toward the end of the study, Shu-May increased her use of various representations, such as providing daily life examples and using illustrations to represent science concepts, her major representations still relied on both linguistic expression and calculation problems.

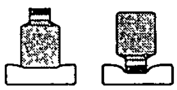
Many researchers(McDiarmind, Ball, & Anderson, 1989; Shulman,1986) have indicated that PCK includes how a teacher represents content to a student's level of understanding. In Shu-May's senior year, she chose two topics for microteaching teaching experiences; one was on the velocity of linear movement and the other was elements with similar properties. For velocity, she spent the majority of her time in explaining the definition of velocity, deriving the formula for velocity, and using problem solving to help students appreciate and remember the concepts she had just taught. In the second microteaching experience, Shu-May introduced important concepts related to "how to categorize the metal elements," reviewed the previous lessons in order to remind students of the properties of the Alkali metal group and Alkaline earth metal group, and introduced the elements by showing and introducing each element to students. After that, she drew the same table listed in the textbook on the board (the purpose of the table was to help students to see the differences in appearance and properties of elements before and after chemical reactions), reminded students of lab safety and some important procedures, demonstrated the first two procedures, and then divided students into three groups to conduct the lab activities. At the end of the lab, Shu-May summarized the students' lab results (Table 1). These teaching representations were very traditional and mainly relied on Shu-May's linguistic expressions.

In her junior high school teaching, she liked to use linguistic expressions, problem solving, demonstration, daily life examples and relevant examples by verbal or visual displays to help students quickly comprehend and then memorize and apply physical science concepts.

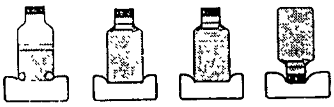
Shu-May liked to use visual displays, either by drawing or showing concrete objects to motivate students in learning new terminology and in appreciating the substance of abstract concepts. Figure 1 shows how Shu-May used drawings to express concepts related to pressure by drawing on the blackboard four bottles laying on a sponge.

> T: The first bottle contains less water, the second, third and fourth bottles are all filled with water, but the fourth one is upside down on the sponge. Compare the depression level of the sponge.

Shu-May used concrete objects to help students appreciate concepts. For example, Shu-May brought a plastic bottle filled with water, with three holes (stabbed with a sharp-pointed pen) covered with tape on the side of the bottle. She asked the students to predict which holes would let water spurt the furthest(the upper, middle, or bottom hole). She then removed the tape from the holes and let the students see the result, and asked them which factor influenced the water spurt. The students stated depth of the water as the answer, and Shu-May explained that the pressure of water is influenced by the vertical force on the



(Note: These pictures were drawn on the textbook)



(Shu-May drew these pictures on the blackboard)

Fig. 1. The comparison between the picture of pressure in the textbook and in Shu-May's teaching.

side of the bottle.

Shu-May mentioned that the abstractness of concepts was the indicator for her to use a visual display; these visual displays ranged from real objects to symbolic displays, such as diagrams. Shu-May explained her timing in using a visual display:

> If it (abstract concept) could be expressed by a real object that will be great...if they do not understand atom, or molecule, I will draw some pictures on the board, or use Styrofoam balls to build a model to explain abstract concepts. If the concepts can be seen, such as the combustion of chemicals ... I will use real objects to show students the results of combustion. Anyway, if there is a real object that can describe the concepts, I will use the real object to show students.

Besides the above instructional representations, Shu-May would improvise with daily-life examples in her teaching. The purpose of using daily-life examples was to help her students appreciate the substance of the science concepts. Sometimes daily-life examples were used to help students understand the application of the concepts she had just taught. For instance, in introducing "pressure", Shu-May first defined what pressure was, and then she said:

> "if two persons sat on a couch, one a fat guy such as Houng Chin Paou (a famous movie star), and the other is Lee-Pin (a skinny student in the class), will they make the couch sink at the same level, or is there any difference in the sink level between these two people ?" All the students laughed when she used names the students knew.

To Shu-May, these examples were relevant to the students so that they could not only appreciate the concepts but also know how to apply them to a new situation.

In another example, Shu-May used a concrete illustration to verify the students' appreciation of science concepts. She asked the students to use two fingers to press the two ends of a ball point pen and then asked the following questions:

> T: Press the two ends of the ball-point pen. If the ball-point pen holds steady within your two fingers, that means the force from the right and left hand sides are equal. If it falls from between your two fingers, which one has more pressure?
>
> SS: The sharp side of the ball-point pen.
>
> T: The larger the area, the lower the pressure; so what is the relationship between pressure and area?
>
> SS: Inverse ratio.

In summary, during the investigation period, Shu-May increased her use of visual displays and daily-life experiences to help students understand science concepts (Table 1). However, these representations were not the main themes in her teaching. In fact, Shu-May mainly used linguistic expressions in the classroom, such as "Let me introduce some terminology, the vertical direction of a force on an object is called a vertical force" and "Today, I will introduce pressure, Pressure = Direct Force/ Area." The researchers believed these linguistic expressions were too abstract and complicated for students to appreciate and to understand. Shu-May did not use more concrete ways to introduce and develop concepts. Besides linguistic expression, Shu-May would demonstrate problem calculations most of the time in order to show students how to apply the concepts to a calculation situation. In this kind of demonstration she expected students to distinguish and know all the variables involved in the concept, and to know how to apply these concepts to a new problem situation. To Shu-May, problem solving exercises fulfilled two purposes: (1) to help students have a better appreciation for the substance of concepts or principles; (2) to help students apply what they learned to a problem solving situation. For instance, when she taught about sodium, she wrote some information on the blackboard.

Atomic number

	Atomic number	Electronic number:
	electronic	Proton number:
Na^{12}_{23}	neutral	Atomic number:
		Neutron number:

> T: So if the atomic number is 11, then what is the proton number?
>
> SS: 11
>
> T: The proton number is the same as the atomic number 11. Then how about the electronic number?

SS:11

T: Did I say that sodium has electronic charge? No. So, the electronic and proton number are all the same; that is 11. How about the neutron number...

SS:....

T: What is the atomic weight?

SS:23

T: As I have said before, almost all the mass is in the atomic nucleus, so all the proton number plus the neutron number is the atomic mass number.

T: If the atomic mass is 23 and proton is 11, then what is the neutron number ?

SS: 12 (Fn940113)

These findings were very similar to data reported by Tuan (1996a) in a previous study; three of the pre-service chemistry teachers expressed the dual purposes of using problem solving as did Shu-May. They used problem solving not only to help students apply the principle/formula to problem situations, but also to help students memorize the principle/formula in order to obtain good grades on examinations.

As summarized by Thorley & Stofflett (1996), a teacher's modes of representation for conceptual change teaching may include linguistic expressions, criteria attributes, exemplars, images, analogies or metaphors, kinesthetic or tactile, and other modes of representations. Although Shu-May used some of the representations, such as using daily-life examples and using illustration to represent concepts, her representations were primarily linguistic expressions rather than other representations. These approaches supported her verification way of organizing her instructional strategies.

C. Shu-May's knowledge of students related to both students' science learning characteristic and ability increased, this knowledge influenced her instructional representations and concept emphases and related variables.

During the study period, Shu-May gained knowledge about students' learning. In Shu-May's senior year, her views of how students learned science were focused on memorization and recitation. She thought students needed to use problem solving to become familiar with concepts. In the teacher education program, the educational psychology course had stressed students' cognitive development. In the instructional materials and teaching methods course, the importance of students' learning by doing science and by experiencing concrete objects had been emphasized verbally. However, these emphases did not seem to have much impact on Shu-May. Her views of students' science learning were very general, and they also reflected Shu-May's view of her own science learning. One excerpt illustrated Shu-May's view of students' science learning at the end of her senior year:

> In the beginning [of the semester], they read the textbook as if they were reading a story. Then they used a red pen to underline the important points. After they had underlined the important points, they would try to understand the concepts. When they practiced problem solving, they were fully able to understand what the concepts meant.

After Shu-May interacted with her students, she started to talk more about how the students' arithmetic and Chinese comprehension ability influenced their science learning. For instance, in a calculation situation, Shu-May mentioned the students could only write "density equals mass divided by volume," but did not know how to calculate the equation. But Shu-May treated this problem as a Chinese literacy problem because the students did not understand what the "unit" of mass meant. To her, there was no way to help them understand the problem. She did not recognize that even though the students had memorized the definition of density, since they did not understand the concept, they could not apply the scientific terminology to a new situation. This represented a more fundamental learning problem than what Shu-May considered. A group of students explained to the researchers why they could not learn well in physical science. One student mentioned:

> It (learning physical science) not only requires memorization but also calculation. We are not good at mathematics and cannot solve calculation problems in physics, so we cannot learn physical science well.
>
> As Shu-May described after the class: I gave them a test on "one meter is equal to how many kilometers." Almost half the class wrote 10km.

Besides being unaware of some of the students' problems in learning new science concepts, Shu-May did not know their previous conceptions or difficulties in learning typical science concepts. Interviews with Shu-May before teaching new topics indicated she did not think of students' preconceptions; she did mention some learning difficulties related to some science concepts. She judged the difficulty level of concepts based on the abstractness of the concepts, such as mole concepts, atom, molecular, etc. However, interviews with Shu-May regarding the teaching strategies she would use to reduce students' learning difficulties, and observations of her teaching, indicated she used few alternative ways to reduce student learning difficulties. What Shu-May used were mainly (1) repetitions, such as using the same analogy (mole is like a dozen of eggs, etc.), or (2) consistently reminding students of the definition of the terminology, such as, "Do you remember I mentioned before, one mole of molecular mass is equal to all the atoms mass in the molecule." Shu-May could have used the students' language and familiar examples or objects to help students comprehend the substance of concepts instead of using repetitious ways.

Shu-May did not really grasp the students' learning difficulties. Only after seeing the students' test results did Shu-May realize their difficulties in learning particular science concepts. Teachers' unfamiliarity with students' preconceptions were also found in studies of other Taiwanese preservice chemistry teachers (Tuan, 1996a) and in U.S. elementary math teachers (Marks, 1990). To Shu-May, the students' literacy (in this case their Chinese language comprehension ability) and arithmetic abilities, and their background in science were more important in influencing them in learning than their preconceptions. She felt they provided the foundation for acquiring new knowledge. In the beginning of the study, Shu-May did not judge whether students would like science and the reasoning behind their science attitudes. Toward the end of the study, Shu-May could explain the students' declining attitude toward science learning instead of just being aware of the phenomena. Shu-May described why the students' attitude toward science decreased dramatically:

> Physical science is difficult. In the beginning of the semester, students liked physical science because of the lab activities. They were willing to listen, watch and memorize science terminology. But! When they faced calculation problems, they totally gave up. (Int 940106-3)

Interviews indicated students responded similarly by indicating "lab is fun" and they were very bad at "problem solving."

Toward the end of the study, Shu-May increased the variety of her concept representations and emphasized their relationships to students.

In the beginning of the study, Shu-May's ideas about the content of a particular topic mainly consisted of several important concepts listed in textbooks. In her senior year, when teaching the unit of constant velocity movement, she described how she would introduce this unit:

> I wrote down four important parts on this topic [in the lesson plan]. First is why we need to learn velocity and the definition of constant velocity movement. Second is the difference between speed and velocity... Third, I will use illustration on S-T and V-T to show students the relationship between position and time, velocity and time, and tell students the difference between these two. (Inv921012)

The observations of Shu-May's microteaching, described in the previous section, were the same as what she said in the above interview. Shu-May tried to help students understand the variables in the concepts using many calculation problems; few representations were used in her microteaching.

Toward the end of the study, Shu-May started to care more about using different content representations and helping students distinguish the difference between the variables of the concepts. For instance, in interviewing Shu-May on her knowledge of pressure:

> Researcher: What do you think this topic (pressure) is about? What is the key point?
> Shu-May: This topic is about the concepts of pressure... I will address this formula (P=F/A), help them appreciate this formula, and explain to the students the relationship between pressure and areas... (Int931007-01)
> Researcher: How would you teach pressure to students?
> Shu-May: [in the textbook], it only described the relationship between pressure and areas, but I think force also needs to be addressed in this topic, so that they can appreciate pressure in relationship to area and force. This organization is better [to show students the whole picture of pressure and the variables related to pressure]. (Int931007-01)

The way Shu-May represented the concepts of pressure are listed in Fig. 1. She drew four pictures on the board instead of the two pictures in the textbook and explained to students how direct force and area influence pressure.

In summary, Shu-May made several changes in her knowledge of students' science learning. In the beginning, she only had general views of students' learning characteristics, and focused on memorization and recitation. Toward the end of the study, her constructed knowledge of students' science learning ability became more focused, especially on how students' previous capacity influenced their science learning. She also could explain students' declining attitude toward science. Knowledge of students' science learning that influenced Shu-May's teaching were that she increased her thinking about and applied different instructional representations, and emphasized concepts and related variables to students in her teaching.

D. Shu-May's thinking on content knowledge became focused and more related to the goals of junior high school physical science textbook. Based on the low ability of the students she taught, she reduced the amount of content covered in her teaching.

In Shu-May's mind, the purpose of her teaching was to reach the goals of the junior high school curriculum, which she believed should be very practical for her students. Thus, all the content knowledge should be relevant and useful to the students in their daily lives.

In Shu-May's senior year, she spent 27 minutes in introducing five different types of velocity calculation problems in class with an emphasis on calculation. In asking her view on chemistry, she described the different disciplines, such as organic, inorganic, analytic, and physical chemistry, and provided detailed descriptions of each discipline.

Toward the end of the study, Shu-May constantly mentioned that the students' low ability made her select a few simple concepts to teach. For instance, in introducing the law of constant composition, Shu-May taught students:

> Shu-May: Let me introduce the law of constant composition. What is the law of constant composition? [She put the following statement on the board]
>
> Law of constant composition: H_2O
> Tap water --- Water
> Sea water --- Water H:O
> River water --- Water Ratio of weight
> Underground water --- Water
>
> [Shu-May started to explain to students]
>
> Shu-May: ... No matter where the original sources of the water, as long as you extract it, pure water will always be H_2O. Do you understand? No matter what the original sources of the water are, as long as we extract it, it will always be pure water.... So the mass between hydrogen and oxygen is 1:8.... It is constant. No matter where the sources of the water are, the weight ratio between hydrogen and oxygen is always 1:8.... Let's turn to page 164[she read from the textbook]. We used experiment to prove the ratio between hydrogen and oxygen in the water. What is the ratio?
>
> SS: 1:8.

This example showed how Shu-May tried to reduce the difficulty level of the concepts and tried to simplify the content for the students. In this case, she only asked the students to remember the ratio between hydrogen and oxygen in water, and carbon and oxygen in carbon dioxide. These two examples were borrowed from the textbook. Except for teaching what was in the textbook, Shu-May did not use calculation problems to show students the law of constant compositions in other complicated chemical compounds.

Toward the end of the study, when interviewed about what chemistry is, what the important concepts in chemistry are, and how chemistry related to other disciplines, she only described what was listed in the junior high physical science curriculum, and never mentioned the additional content in her college chemistry courses. The same responses were obtained when interviewing her on the topic she was teaching. What concerned her most was how to introduce science concepts in a simple way that could be appreciated by her students.

The above findings were also found in studies of other preservice Taiwanese science teachers (Tuan, 1996b) during their senior year of practicum courses. These preservice teachers related what they had learned in the chemistry department and the topic they were teaching. However, after one-month of classroom teaching experience, these teachers' responses to the previous questions shifted to closely following the content knowledge listed in the junior high school physical science textbooks; the relevance of college chemistry to junior high school textbook topics did not seem to greatly influence their science teaching. Shu-May and other pre-service chemistry teachers indicated "what you have learned in the chemistry department is too abstruse to teach in junior high school physical science."

The changes in Shu-May's thoughts about content became more and more focused on the junior high school curriculum. In the beginning of the study, although Shu-May thought teaching should relate to students' needs, her awareness was not reflected in her thinking or teaching of particular content topics. Toward the end of the study, Shu-May would constantly question the difficulty level of the concepts, and decided to teach simple concepts without extensive explanation.

2. Factors influencing Shu-May's PCK development

Analyzing Shu-May's data from her senior year to first year of teaching, the researchers identified many factors which influenced the development of her PCK.

A. Shu-May's perceptions toward science teaching and students' science learning influenced each other and reinforced her presentation of science concepts in a verification way.

Shu-May's teaching was characterized by using the verification method of introducing science concepts from her senior year to first year of teaching; this was influenced by her beliefs about science, epistemology, pedagogy and her perceptions of students' science learning.

Although she did not have any problems with classroom discipline and students' learning ability in her microteaching experience, she thought the best way to present content was by using a "traditional teaching method." During Shu-May's internship experience, she started to be concerned about students' learning abilities; however, her perceptions regarding the students' learning and ways to maintain the students' motivation reinforced her continuous in using verification ways in teaching.

In a low-ability learning environment where classroom discipline problems occurred easily, Shu-May believed the best way to present content was to use simple and repetitious ways to present her content knowledge to the students. The students' achievements in her science class declined as the amount of calculation problems increased on the school tests, due to students' lack of arithmetic ability and their lack of motivation. Shu-May tried to solve these problems by spending time helping them to appreciate the substance of science concepts and using verification instruction to have the students memorize the content knowledge to help them obtain higher achievement scores. Achievement scores were the indicators Shu-May used to check students' understanding; it also became the goal in Shu-May's teaching.

> Shu-May: Their (students) backgrounds were not good, they did not know. So, you have to force them to memorize some facts.
> Researcher: What is your orientation toward physical science teaching?
> Shu-May: Helping them understand and then helping them get good grades. (Int 930929)

She seemed to treat science as a body of terminology (or factual knowledge) for students to know. She also thought that students' mastery of previous knowledge would influence their learning of new knowledge; this reinforced her use of teaching strategies to help students memorize scientific terminology.

B. Shu-May was insensitive in judging the appropriate goals of the lessons and the students' needs for understanding, which made her content representations beyond the students' comprehension level.

An important feature of PCK is to identify the importance of the goal of the topic to match the students' level of understanding, and then decide the appropriate instructional methods to reach the goal of the chapter (Shulman, 1986). Although Shu-May increased her thinking and practicing regarding the representations of the content to students during the investigation period (see Table 1), she did not effectively judge the appropriate level of content knowledge, the goals of lessons, or identify the comprehension levels of the students; these conditions made her content explanations and representations exceed the comprehension level of her students.

When the researcher discussed with Shu-May the importance of addressing categorizing skills for the students, she responded:

> I only taught them what was addressed in the textbook. I did not tell them the goals of this chapter. (Int940321-07)

> In the unit on density, Shu-May described:
> I kept teaching the students the formula D=M/V....My colleagues did not tell me I have to teach M=DxV or V=M/D... I found a problem in a reference book about the density of mixed solutions; I really don't know whether I should teach this problem or not. If I did not teach it, then I did not address any important part in this unit. If I taught it, I was afraid that the students could not understand it. (Int930929-15)

If students understood the concept of density, they could apply the density concept to many situations. Thus, the teaching emphasis should have been placed in various representations for students to construct density concepts instead of helping them memorize different forms of the density equation.

Several variables influenced her teaching. Shu-May's previous tutoring experience in college influenced her in constructing a novice view of the junior high school physical science curriculum. She thought being familiar with the concepts covered and organized in the junior high school textbooks was the goal of the curriculum. Helping students succeed on school examinations was considered by Shu-May to be a more important goal than helping students to understand science concepts and applying them in their daily lives. These factors influenced her in defining her goals for the lessons.

Another variable influencing her teaching was her insensitivity in judging students' needs for understanding. Analyses of Shu-May's questions in her senior year and her quizzes in the first year of teaching indicated most of Shu-May's questions and quizzes were at the memorization level, such as write down the Chinese name for sodium, and write down the chemical formula for water. Fewer than half of the students could reach a passing grade (60 points) on her quizzes. When students faced calculation problems, most of them gave up trying. We interviewed Shu-May about the reaction students had, and she related students' motivation to their confidence in achievement in the science class. Her thoughts of using quizzes was that they could both help her check students' comprehension and help students success on the school examinations. She believed that after having success on school examinations, students' motivation toward learning science would be sparked. Therefore, Shu-May thought that frequently conducting quizzes would push students to memorize scientific terminology in order to get higher scores on the examinations. When Shu-May saw students' failing on these tests, she was unable to diagnose the reasons students did not understand the concepts. Therefore, she could not identify more appropriate ways to present content to these students.

C. Shu-May showed evidence of comprehending concepts and procedures related to pedagogical knowledge in her college methods courses. Her inability to apply them to her teaching situation and later lack of recall of them, however, indicated she did not develop a functional understanding or use of much of the pedagogical knowledge taught.

Analysis of Shu-May's teaching performance showed that her teaching strategies did not change during the investigation period. The only change was in the frequency of some of her teaching activities, such as showing more concrete objects and using drawings or daily-life events to explain concepts.

As mentioned before, the first author had covered many science teaching methods such as lab teaching, conceptual teaching, discrepant event teaching, learning cycle and creative science teaching in the chemistry teaching methods. The author tried to use discussion and role modeling in order for the preservice teachers to appreciate the meaning and application of each teaching method. When she was studying these teaching methods, she could explain and discuss ideas with her classmates. In Shu-May's report, it seemed that she was familiar with these teaching methods. One example shows Shu-May's assignment on her perception of the learning cycle:

> In planning the lesson, a teacher has to think of the students' perception, and then provide a learning environment and teaching resources, let the students conduct labs and learn concepts, and provide opportunities for the students to discuss ideas so that they can apply the concepts to new situations... The role of the teacher is to diagnose, facilitate, and provide a learning environment. (assignment-014)

Unfortunately, toward the end the of the study, Shu-May could not remember most of the teaching strategies or pedagogical knowledge from her college courses related to thinking, talking and performing related to her teaching.

> Researcher: Can you think of any teaching methods learned in college for preparing you in teaching?
> Shu-May: All the theories learned in college seem remote to me. Maybe I have integrated all the pedagogy learned in college or I have totally forgotten it. I do not know... I have forgotten the learning cycle you just mentioned. (Int940321-03)

Researchers could not trace the topics covered in the methods courses to her classroom teaching. What she often taught in the class represented content knowledge for students to quickly appreciate and remember. Any conceptual change teaching methods, discrepant events, or learning cycles were rarely found in Shu-May's teaching. Shu-May did not develop a functional use of most pedagogical knowledge taught in her college courses; therefore, she was unable to apply it in her first-year of teaching.

D. The culture norms Shu-May perceived in different teaching contexts either reinforced or impeded her perception and performance in science teaching.

In Cochran's model (Cochran, *et al.*, 1993) teachers' knowledge of culture and environment also influenced the development of their PCK. Feiman-Nemser & Floden (1986) defined teaching culture as "embodied in the work-related beliefs and knowledge teachers share - beliefs about appropriate ways of acting on the job and rewarding aspects of teaching, and knowledge that enables teachers to do their work (p.508)."

In Shu-May's senior year, she was enrolled in a context where chemistry content knowledge learning was the top priority. In addition, all the students she faced were her classmates; no learning problems or classroom discipline problems occurred in the teaching context. Her perceptions of using the traditional lecture style to present science matched with the existing teaching culture, which reinforced her to mainly address in-depth content explanations in her two microteachings. Shu-May's idea of helping students overcome their learning difficulties at this time was by re-teaching many times until students could understand the meaning. She was not involved in a context that had any pressure, time limitations, or a prescribed curriculum pace.

However, when she was enrolled in her practicum school, the environment where examinations, competition and covering a prescribed curriculum at a set pace were practices and norms very similar to those described in several research reports (Abell & Roth, 1992; Brickhouse & Bodner, 1992; Sanford, 1988), Shu-May tried to adapt to these practices and culture norms. As Shu-May explained to the author why she could not re-teach to confirm students' understanding, she said:

> [In the beginning] I was concerned about whether students understood the concepts or not. If they did not understand, I would teach them again and again, until they grasp at the concepts. But I can not use this way now. I was too idealistic before... I realize the students' ability was low beyond my imagination. No matter how simple a concept, there were always some students who did not understand it... School also provided a prescribed curriculum pace, and examinations, I have to catch up to the prescribed curriculum. That problem is a reality problem. (Inv931104-02)

In addition, Shu-May's perceptions of using achievement scores to motivate students to learn reinforced her adaptation to the cultured norms. This teaching culture and her perceptions toward teaching and learning further reinforced her thinking that helping students get good grades on examinations was her main goal in teaching. These goals could also provide intrinsic motivation for teachers to choose teaching activities designed to foster achievement (Mitchell, Ortiz, & Mitchell, 1982). These goals also influenced Shu-May to help students memorize science concepts instead of helping them appreciate the substance of the concepts and how science concepts could apply to their daily lives.

IV. Discussion and Conclusions

Investigation of the nature of a beginning Taiwanese science teacher's PCK revealed three features. These are integration, relevance, and specificity. Toward the end of the study, Shu-May's thinking and performance in teaching had more integration of content, students and pedagogy. She also tried to make content representation more relevant to the students. Relevancy also influenced Shu-May to match content teaching with the students' level by teaching simpler content using repetition. However, Shu-May's thinking regarding the importance of content relevancy did not necessary reflect her ability to appropriately present content to the students' level. Thus, there are some discrepancies between what Shu-May thought and her appropriate teaching performance. In terms of the specific nature of PCK, Shu-May's knowledge of students changed from a general view of students' learning to a more specific understanding of their content learning ability. Her content knowledge also changed from a general view of the physical science discipline to specific descriptions of what students should know on each topic. Again, the above features of the development of Shu-May's PCK revealed the tendency of Shu-May to think about and improve her teaching. There often is a discrepancy between what teachers say they would like to do and their teaching performance, in other words, they lack the functional knowledge to transfer what they know into appropriate teaching performance. Science teacher educators need to help preservice and beginning science teachers not only to think of the important issues related to PCK but also to help them perform functional PCK in their teaching situation.

The development of Shu-May's PCK from her senior year to the first half of her teaching year was what Berliner (1988) termed, the "novice stage." That is, Shu-May still used certain rules -- the verification teaching strategies to teach content, even though she was aware of the low ability of her students. She tried to use different instructional representations on her students but lacked understanding and awareness for judging the appropriateness of the representations. On the other hand, Shu-May's increasing knowledge of the students started her to think about the teachability of the content; her use of steady and simplified content teaching strategies in the class were in line with Kagan's (1992) model on the acquisition of knowledge of students, shifting attention to students, and developing standard procedures. However, Shu-May's constructed knowledge that related to students' science learning was not appropriate to what really caused the students' science learning problems.

Applying Tuan's (1996c) microscopic views of the development of Shu-May's PCK, her teaching strategies were organized into introducing science concepts from the textbook to help students memorize concepts. Toward the end of the study, her main teaching strategies were the same, but she increased her use of some strategies to help students memorize concepts. Shu-May's instructional representations increased in both variety and frequency, such as providing daily-life examples and illustrations to present science concepts. Shu-May's knowledge of students increased both in students' science learning characteristics and ability. Her thinking and teaching of content became more focused and related to the junior high school physical science textbook. Other features of PCK such as curriculum knowledge and knowledge of assessment did not show obvious development; this might be related to the data collecting procedures which did not address these aspects of data. Future study is needed to address these features of PCK. In terms of the last feature of a PCK -- teacher's knowledge of context, it became one of the factors influencing Shu-May's PCK development, and is discussed later.

Shu-May lacked recall of functional pedagogy knowledge learned in college. Her thinking on content knowledge became focused and more related to the goals of junior high school physical science textbooks, and her knowledge about students increased in both students' science learning characteristics and ability. These three domains of knowledge integrated together influenced her in thinking and performance in instruction of the teaching context. Of course, there is no strong evidence to say Shu-May's pedagogy and content knowledge disappeared, but it is evident these two domains of knowledge were not functional when she thought of and performed PCK. One way to think of Shu-May's decrease of thinking content and pedagogy knowledge might be due to her learning experience in college. She memorized instead of making sense of this knowledge; therefore, it was easy for Shu-May to forget concepts and use was likely never functional.

Factors influencing the development of Shu-May's PCK were her perceptions toward science teaching and students' science learning, insensitivity in judging appropriate goals of lessons and students' understanding, declining retention of pedagogical knowledge, and the different cultural norms she perceived in different teaching contexts.

Shu-May's PCK revealed her view of the nature of science. Her perceptions of science seemed to be that of a logical positivist: that growth in knowledge occurs through accumulation (Abimbola, 1983). This perception reinforced her representation of the scientific knowledge in logical sequential ways and her use of the verification method in presenting science content. A modern view of the nature of science, such as temporary, inquiry and societal nature of scientific knowledge (AAAS, 1993) was not addressed in Shu-May's teaching. She did not present the syntactic and substantial nature of the content discipline (Grossman, Wilson, & Shulman, 1989; Shulman, 1986) to her low ability students, which might have impeded her in using a variety of ways to represent science content instead of simply using lecture style. The current chemistry teacher education department did not offer experiences with these aspects of science to beginning science teachers. The teacher education program could address the nature of science and the syntactic and substantive nature of science disciplines in the science content courses; this might help beginning science teachers or future preservice science teachers to gain more understanding of the nature of science and the nature of content discipline and facilitate the development of their PCK.

Shu-May's inadequacy in judging the ability of her students to learn science, such as what students can know, what they need to know, and how to help them learn science strongly influenced her teaching. Although Shu-May gained some knowledge of students, she still needed to gain understanding of some essential components that directly influenced the students' science learning in order to know how to use appropriate ways to teach content. Because Shu-May could not diagnose her students' learning ability and needs, she had difficulty in selecting appropriate lesson goals.

Shu-May's declining retention of pedagogical knowledge learned in college and her probable lack of functional pedagogical knowledge influenced her to use the same teaching strategies. If Shu-May could have remembered the teaching strategies taught in the methods course, then when she faced students' with low motivation in science learning, she could have applied other teaching strategies to facilitate students' learning. We think, although Shu-May heard about the kinds of science teaching strategies that could have helped her, these teaching strategies were not necessarily meaningful for her in a functional way. Shu-May did not have opportunities to practice these teaching strategies in teaching contexts. Therefore, she did not know how successful these teaching methods could be of the appropriate ways to use them.

The last factor influencing Shu-May's PCK development was the culture norms she perceived in her teaching. Feiman-Nemser & Floden (1986) addressed a teacher's socialization, investigating the transmission of beginning teachers' beliefs, knowledge, attitudes, and values to the norms of the teaching culture. Shu-May's college learning experience, especially her pedagogical knowledge, seemed inactive in her school experience, corresponding to the findings by Zeicher & Tabachnick (1981). Her view of the students' ability to learn also influenced her content teaching, supporting previous research that pupils play an important role in influencing a teacher's behavior (Zeichner, 1983). Although Shu-May had pedagogical knowledge and could verbalize this knowledge in college, this pedagogical knowledge did not seem to have real meaning for her in the classroom, nor did it become part of her root values; therefore it was easily diluted by the teaching culture. However, as Feiman-Nemser & Floden (1986) have indicated, teachers do not have to passively adopt the norms of the teaching culture; they can also change the culture based on their beliefs and practical knowledge.

Therefore, there are two ways to think about this finding. One is that when Shu-May or other beginning science teachers enrolled in the teacher education program, they had experience in memorizing all the factual knowledge in both the content and pedagogy courses. This factual knowledge was not meaningful for Shu-May. Therefore, she did not apply it to her classroom teaching. It is also possible that courses offered in science teacher education programs did not create an environment for preservice science teachers to question their previous perceptions on the nature of science and on science learning. Therefore, when they taught science in school, they applied what they had experienced as high school students, instead of applying what they learned in the science teacher education program.

V. Suggestions

As we learned from Shu-May in the development of her PCK and the factors influencing her development, we generated the following suggestions for future science teacher education.

Research supported our finding that beginning science teachers give more attention to their pedagogy instead of content (Duffee & Aikenkead, 1992; Lederman & Gess-Newsome, 1991; Tuan, 1993). There were many opportunities for Shu-May to improve her science teaching if she had thought more about the nature of science, and the substantial and the syntactic structure of the content discipline.

Teacher education programs should address the nature of science and the syntactic and substantive nature of science discipline in the science content courses. Teaching methods courses need to address the nature of science and science teaching strategies related to the substance of PCK, such as strategies, appropriate instructional representations, curriculum knowledge, ways to diagnosis students' understanding, and ways to determine students' learning characteristics on different subjects. These emphases would help future preservice science teachers to develop their PCK.

As the finding indicated during the internship experience, the beginning science teacher became aware of the importance of integrating her content knowledge to the students' level of understanding. Hopefully, this teaching condition will create opportunities for science educators to introduce and to help beginning science teachers to construct appropriate PCK bases during their supervision and their regular seminars. Topics could be covered in the internship seminar that could relate to thinking of different instructional strategies, appropriate representations, the nature of science related to science teaching, diagnosing students' understanding, and overcome students' learning difficulties.

To provide meaningful teaching methods for preservice science teachers, we need to arouse their attention to the importance of different domains of knowledge in order to facilitate their developing PCK. As Feimer-Nemser & Folden (1986) illustrated, the most immediate genesis of the teaching culture is the classroom context. A teacher's PCK is influenced by the student-teacher interaction in the classroom. Thus, helping preservice teachers have early field classroom teaching experiences and more discussions on relating content teaching and diagnosing students understanding are ways of improving a teacher's PCK development. Teachers need to have opportunities to practice and reflect on what they have learned in their methods course in order to appreciate the substance of each teaching strategy and various instructional representations. What has not been learned in a useful way can not be applied in the teaching context.

If we can educate preservice teachers such as Shu-May and help them construct appropriate perceptions of their content disciplines, the nature of science, and current science teaching strategies, and help them have a successful experience in learning how to use these science teaching methods in the classroom, we can then expect our future teachers to change the science teaching culture instead of the culture diluting what they have learned in the university. Constructing a professional developmental school where the opportunities, support and freedom to practice an appropriate science teaching culture could also help the beginning science teachers to have freedom to master their science teaching.

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Appendix 1: Interview Protocol

Interview questions at the beginning and at the end of the semester:

1. What does an excellent science teacher mean to you? How do you become an excellent science teacher ?
2. How did you become a teacher? What are your future plans?
3. What kind of teacher do you think you are? You can use a metaphor to explain your answer.
4. What does teaching mean to you? What issues in teaching do you think of often? What issues about students do you think of often?
5. What do you think of often about chemistry? Could you express your thinking about chemistry to me?
6. What do you think of often about physics? Could you express your thinking to me ?
7. What do you think of often about physical science? Could you express your thinking about physical science to me?
8. What are your pedagogical beliefs? What does your teaching look like in an ideal situation?
9. What is your perception of students' physical science learning? Do you have any strategies for changing students' learning habits?
10. What are your expectation on how students should learn?
11. What are the goals students need to reach after taking your physical science courses?

Interview questions before each class teaching:

1. Could you explain the content of this unit? Please explain in detail the knowledge you have on this topic.
2. How do you teach this unit? What's your teaching flow?
3. How do you prepare this unit? What factors did you consider? What kinds of difficulties might you face? How do you plan to solve these difficulties?
4. What do you expect students to learn from this unit? Why?
5. Do you have other ways of presenting this unit?

Interview questions after each classroom teaching:

1. What do you think was covered in this unit? What change would you like to made about the responses you provided in previous interview?
2. How do you view your own teaching?
3. How did students learn in this unit? How did you help them?
4. Do you have other ways of presenting this unit?

一位初任台灣國二理化教師學科教學知識之發展研究

段曉林 *　高榮成 **

* 國立彰化師範大學科學教育研究所

** 台東市新生國中

摘　要

本研究的目的在檢驗一位初任女教師在大四至大五上學期期間，其理化的教學特質與成長。研究的理論架構，採微觀與巨觀的學科教學知識。研究方法採質的研究。資料收集包含教室觀察、晤談與文件收集。研究進行期間，由個案質淑美的大四教材教法與實習課，至大五上學期期末止。資料分析主要採分析歸納法。研究發現顯示，淑美的學科教學知識特質包函教學策略與教學表徵兩部份。她的教學策略主要採用驗證式的方式教授科學概念。淑美的教學表徵包涵，口語表達、解題演練、示範、生活實例、利用口語與圖示等方式。淑美的學科教學知識發展呈現出統整、關聯、與具體的特徵。在研究結束時她的教學思考已經能同時整合學科、教學、與學生。在教學中她試圖將學科知識與學生的理解做關連。雖然她企圖使用不同的表徵使得學生能理解概念，但這些表徵未必能符合學生的理解程度。她的學科知識亦從對理化科課程一般的看法，到學生在每單元大致需瞭解到的目標。最後，影響淑美學科教學知識發展之因素，包括其對科學教學與對學生的知覺，她對於檢驗學生的理解程度與合宜的課程目標不夠敏銳，她本身對教學知識的淡忘，和在不同的教學文化情境中所造成的教學重心差異。文章最後亦對於未來科學師資培育做一建議。