



A Comparison of Experienced and Preservice Elementary School Teachers' Content Knowledge and Pedagogical Content Knowledge about Electric Circuits

Jing-Wen Lin

National Dong-Hwa University, TAIWAN

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ABSTRACT

This study investigated the differences between Taiwanese experienced and preservice elementary school science teachers' content knowledge (CK) about electric circuits and their ability to predict students' preconceptions about electric circuits as an indicator of their pedagogical content knowledge (PCK). An innovative web-based recruitment and data collection technique were involved to purposeful collect samples totalling of 76 experienced teachers, 85 preservice teachers, and 438 students. Confidence assessment was used to assist in identifying alternative conceptions. Results indicated the experienced teachers possessed more acceptable CK with higher confidence than the preservice teachers. However, both groups' predictions of students' conceptions about electric circuits were not significantly different in two-thirds of the test items, and their learning experiences were the main source used to predict students' preconceptions. This study suggests establishing science teacher qualification to enhance preservice teachers' CK, and helping both preservice and inservice teachers become aware of their students' preconceptions were needed.

Keywords: confidence, content knowledge, electric circuits, pedagogical content knowledge, teacher education

INTRODUCTION

Ausubel (1968) suggested that the fundamental principle of education psychology was to ascertain what students know and teach them accordingly. This brief suggestion served as the foundation for realising the importance of students' preconceptions, for enhancing teachers' content knowledge (CK) and pedagogical knowledge (PK) as the foundation for teachers' pedagogical content knowledge (PCK), and for the conceptual change approach in designing effective constructivist-oriented teaching based on what students' already know (Duit & Treagust, 2012; Larkin, 2012). Numerous studies have pointed out that it is a challenge for teachers to transform their CK and PK into PCK and to enact it into practices (van Driel & Berry, 2012). Although there is no consensus about the components of PCK models (Kind, 2009), Schneider and Plasman (2011) suggested that science teachers' learning progression of

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Correspondence: Jing-Wen Lin, *Department of Education and Human Potentials Development, National Dong-Hwa University, No. 1, Sec. 2, Da Hsueh Rd. Shoufeng, 97401 Hualien, Taiwan.*

✉ jingwenlin@mail.ndhu.edu.tw

State of the literature

- Understanding students' prior conceptions is the first step for developing science teachers' learning progression of PCK, but there is a lack of larger sample size studies to explore the pattern of teachers' predictions of students' conceptions.
- Research on one-to-one tutoring found that tutors predicted students' conceptions based on their own learning experiences, and had difficulty monitoring their students' conceptions.
- Diagnosing teachers' and students' confidence in answering questions along with the conceptual diagnostic instruments not only helps researchers identify teachers' and students' conceptions more accurately but also helps teachers and students to be aware of their own conceptions.

Contribution of this paper to the literature

- Although experienced teachers possess more acceptable content knowledge with higher confidence than preservice teachers, both experienced and preservice teachers shared the same typical alternative conception about Ohm's law.
- Using web-based confidence assessment help researchers collect reasonably large samples of teachers and students data. This study found both experienced and preservice teachers are insensitive to students' preconceptions. Teachers' insensitivity does not appear to change with teaching experience and advanced science education study.
- Experienced and preservice teachers' learning experiences might be the major source on which they predict students' preconceptions.

PCK starts from considering students' thinking about science (e.g., students' prior knowledge, initial science ideas, previous experiences). Van Driel, Berry, and Meirink (2014) stated that "At the heart of PCK lies what teachers know about how their students learn specific subject matter or topics and the difficulties or misconceptions students may have regarding this topic" (p. 849). Therefore, teachers' awareness of students' preconceptions and learning difficulties could be important starting points to assess teachers' PCK.

Some countries have regularly published teacher materials to help science teachers assess students' conceptions and integrate knowledge of them into planning lessons (e.g., Keeley, Eberle, & Farrin, 2005); however, this is not the case in Taiwan. Furthermore, the proportions of students' misconceptions vary by area and learning stage, but continued assessment is labour intensive. A time-efficient online assessment and database for detecting the dynamic changes of students' conceptions is needed for use by teachers and researchers. The aim of this study was to explore (a) the differences between experienced inservice and novice preservice elementary school science teachers' topic-specific CK and (b) the first step of these teachers' PCK learning progression about a well-documented idea in a city with rich educational resources, Greater Taipei. These teachers' conceptions about electric circuits and their predictions of the students' prior knowledge about electric circuits are assumed to be the indicators of the teachers' topic-specific CK and PCK, which can be investigated by established tests and surveys and are suggested by some researchers (Lin, 2016b; Jüttner & Neuhaus, 2012; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). This study used a web-based confidence

assessment to assist in identifying alternative conceptions of reasonably large samples of teachers and students more accurately and immediately. The research questions (RQ) that guided this study were:

1. What are the experienced teachers' (ETs') and pre-service teachers' (PTs') understanding and confidence in answering questions about electric circuits? Does any statistical difference between the ETs' and PTs' CK exist?
2. What are the similarities and differences between the Grade 3 students' answers to these questions and the ETs' and PTs' predictions of the students' preconceptions? Does any statistical difference between the ETs and PTs predictions exist?

LITERATURE REVIEW

Science Teachers' Content, Pedagogical, and Pedagogical Content Knowledge

Shulman (1987) indicated that teachers should have a repertoire of knowledge consisting of CK, PK, and PCK. CK is specific to the domain and topic being taught and is assumed to come from the science courses in a teacher education program from the faculty of sciences. PK is the instruction-related knowledge assumed to come from the education courses dealing with curriculum, learning, teaching, and assessment from the faculty of education (Asikainen, & Hirvonen, 2010). Van Driel et al. (2014) selected a simple model to present teacher knowledge. PCK is the heart in this model and is in a mutual relationship of CK, PK, and knowledge of context (e.g., school, students, community). In other words, PCK is related to learning and teaching a specific topic in a specific context with specific students. It is assumed to be a personal transformation of PK and CK into PCK that occurs *in situ* during repeated, authentic teaching experiences with or didactics of a specific topic.

Some teachers hold conceptions incompatible with scientific views that are similar to those held by their students (Duit & Treagust, 2012; van Driel et al., 2014). Furthermore, some teachers' alternative conceptions might strengthen students' misunderstandings (McDermott & Shaffer, 2000). Kind (2014) claimed that even teachers with Bachelor of Science degrees and diverse backgrounds (i.e., chemists, physicists, biologists) for teaching specialist science subjects are not enough. A solid CK background is an essential condition, but it is not a sufficient condition for teaching science effectively in elementary schools (Oh & Kim, 2013). Schneider and Plasman (2011) suggested that understanding students' prior conceptions is the first step for developing science teachers' learning progression of PCK, but several studies indicated teachers are insensitive to students' prior conceptions as a critical constructivist component of knowledge about learners (Lin, 2016b; Lin & Chiu, 2010; Chi, Siler, & Jeong, 2004; Liang, Chou, & Chiu, 2011). Research on one-to-one tutoring has found that tutors predicted students' conceptions based on their own personal learning experiences, overestimated the accuracy of students' conceptions, and had difficulty monitoring their students' conceptions (Chi et al., 2004; Herppich, Wittwer, Nückles, & Renkl, 2013). There is also a lack of larger sample size studies to explore the pattern of teachers' predictions of

students' conceptions. Jüttner and Neuhaus (2012) suggested there is value in developing PCK instruments for measuring teachers' knowledge of students' errors and ways for dealing with them.

How and where elementary science teachers develop their CK and PCK are important but not well documented (Kind, 2009; van Driel & Berry, 2012). This study attempted to address this void by exploring and comparing the ETs' and PTs' CK and their predictions of students' preconceptions about electric circuits to better understand teachers' knowledge of PCK across the career continuum via a web-based mental models diagnosis (WMMD) system (Wang, Chiu, Lin, & Chou, 2013). The WMMD allowed the assessment of PTs' and ETs' CK and their predictions of students' CK in an efficient, reliable, and valid manner.

Confidence Assessments to Assist in Identifying Alternative Conceptions

Determining an instrument that might help diagnose individuals' alternative conceptions is an ongoing concern. Multiple-choice instruments have become a predominant assessment in science education, but guessing the correct answer based on probability and incorrect understating and reasoning are concerns with this method. Some researchers (Lin, 2016a; Caleon & Subramaniam, 2010; Kirbulut, & Geban, 2014) have pointed out a factor that might lead to the inaccuracy of these traditional test results: overestimating students' performances because some students might answer correctly but with uncertainty. It is important to distinguish between students who actually understand from those who answer the question by guessing. The treatment for students' understanding might be significantly different between those with firmly held alternative conceptions and those with lack of knowledge.

Treagust (1988) developed a two-tier diagnostic instrument that partially addressed this concern in which the first tier involves multiple-choice *content* questions and the second tier involves the possible *reasons* for the answers given in the first tier. However, concern about inaccurate estimates still existed. Thus, a three-tier diagnostic instrument was proposed in which the third tier diagnoses students' confidence or certainty of response (Lin, 2016a; Caleon & Subramaniam, 2010; Kanli, 2014; Kirbulut, & Geban, 2014). Researchers in science education have applied the measurement of confidence for several purposes, such as making distinctions between alternative conceptions from either a lack of knowledge or simply guessing. Furthermore, the results of students' confidence ratings can reflect the strength of their conception and help researchers avoid overestimating student performance.

The measurement of confidence has usually been presented as a Likert-type scale to identify students' degree of certainty when answering questions. Caleon and Subramaniam (2010) suggested that, when students' degree of certainty is high (above median), their correct answers should be considered as actual understanding whereas similar certainty for wrong answers should be considered as misplaced confidence toward their deep-rooted alternative conceptions. In contrast, when the degree of certainty is low (below median), their correct answers should be considered as simply guessing otherwise the wrong answers will be

considered as deficient knowledge. They found that students in their study held 21 significant alternative conceptions about waves, of which approximately half were spurious conceptions. Kanli (2014) also used confidence ratings to precisely identify preservice and in-service teachers' basic astronomy conceptions. Accordingly, diagnosing teachers' and learners' confidence in answering questions along with the conceptual diagnostic instruments not only helps researchers identify teachers' and learners' conceptions more accurately but also helps teachers and learners to be aware of their own conceptions.

Students' and Teachers' Understanding about Electric Circuits

The conceptions of simple and series electric circuits held by students at all school levels and their teachers have been extensively studied, which provides a well-documented area for exploring preservice and inservice teachers' topic-specific CK and PCK. Predominant types of students' conceptions of simple and series electric circuits include unipolar, clashing-currents, crossing-currents, attenuation, sharing, and scientific models (Chiu & Lin, 2005). Students who lack understanding of a complete path for current flow hold a unipolar model that assumes the electric currents flow from one terminal of the battery into the bulb. It is generally accepted that the unipolar model is young students' developmentally earliest model (Allen, 2010). The clashing-currents model assumes that the electric currents flow from both battery terminals and run into each other when they reach the bulb. The crossing-currents model assumes the electric currents flow from both battery terminals, similar to the clashing-currents model, but take alternating turns flowing to the bulb. The attenuation and sharing models are closest to the scientific model, which specifies the electric current flows from one battery terminal through the bulb to the other terminal and is identical throughout the series circuit. The attenuation model assumes that the electric current is consumed by the bulbs, such that the first bulb is brighter than the second bulb; the sharing model signifies the electric current is shared equally by two bulbs.

ETs and PTs also hold these alternative mental models of electric circuits (Pardhan & Bano, 2001; Shen, Gibbons, Wieggers, & McMahan, 2007). Furthermore, there are some similarities between teachers' and students' conceptions. For example, Shen et al. (2007) found that some of the K-8 science teachers held that the closer the bulb was to the battery, the brighter the bulb would be. Surprisingly, formal instruction can lead students to develop alternative conceptions (Lin & Chiu, 2007); therefore, understanding the differences between teachers' awareness of the conceptions held by themselves and their students might help enact more effective constructivist-oriented instruction about electric circuits.

METHODOLOGY

This study involved multiple steps to survey students' conceptions of electric circuits, ETs' and PTs' conceptions of electric circuits with their confidences, and ETs' and PTs' predictions of students' conceptions. The following sections specify the procedures.

Context

Elementary school teachers in Taiwan are typically hesitant to teach science because of their limited CK and PCK (Lin, 2016b). Therefore, if an elementary teacher volunteers to participate in a teacher professional development or a master's program in science, it is assumed that he or she possesses motivation to become a high-quality science teacher. The proportion of teachers with a master's degree in Taiwan is increasing year by year in response to education policy intended to ensure high-quality education. A large-scale national survey (Wu, Cheng, Tuan, & Guo, 2011) on the demographics of science teachers indicated that 7.5% of teachers ($N = 2,406$) held a Master of Science degree (including science education). Only a small minority of inservice teachers have the opportunity to learn about the PCK's elements and the importance for good science teaching. Because Greater Taipei is the area with the most educational opportunities and resources in Taiwan, its teachers and schools are of higher quality than the national average (Department of Statistics in Ministry of Education, 2011). The ETs in this study were typical examples of high-quality inservice teachers in Taiwan.

PTs must pass the national examination of teacher certification (Wu, 2003), which is extremely competitive due to limited public school teaching positions. The certification examination does not emphasize science CK or PCK for elementary teachers since they are expected to teach all subjects. Recently, the government has become aware of the deficiency of PTs' science CK and PCK. Where and how new and practicing teachers develop science CK and PCK is not well documented; therefore, there is insufficient information to design and carry out effective professional education and development programs. This study purposively selected ETs with both a science education background and science teaching experiences – as representative of highly motivated teachers admitted into the advancement programs – and PTs with generalist content backgrounds and limited teaching experiences as participants. The results could help science teacher educators to understand both inservice and preservice science teachers' CK and PCK qualities, which could then inform revision of science teacher education programs.

Participants

Three groups of participants, 76 ETs, 85, and 438 Grade 3 students were purposively sampled in this study. All participants and authorities were informed about the research and voluntary involvement in keeping with the research ethics practices in Taiwan.

The ETs from Greater Taipei were selected via PTT (telnet://ptt.cc), the largest Bulletin Board System in the world (Chang, 2009). *Experienced*, in this study, refers to those teachers who have both experience teaching science and a master's degree in science education. Gift vouchers were offered to a randomly selected subsample of those who met the criteria of ET and volunteered to complete the diagnosis instrument. Among the 76 ETs who participated in the study, 54 were science major and 22 were nonscience in their undergraduates. For the purposes of this study, it was assumed that these teachers had reasonable understanding of

teaching science and were representative of high-quality teachers in Taiwan because of their education and teaching backgrounds.

The PTs consisted of 7 science majors and 78 nonscience majors recruited from the elementary teacher education program of a public university in Greater Taipei. All PT participants had academic credit for teaching methods and materials in science and technology courses. They were representative of the prospective teachers who complete the science teaching requirement and might have the opportunity to teach elementary school science, which does not require that they have a science major.

A total of 438 Grade 3 students (about 9 years old) who had not received formal instruction about electric circuits were selected from two of the largest elementary schools in Greater Taipei that aligned with the participating teacher experiential context and potential future teaching assignments. Most of the students came from middle or upper-middle socioeconomic level families; the academic achievement of these students was representative of the student population in Greater Taipei, which is amongst the highest in Taiwan (Chen & Liu, 2008).

Instruments

The electric circuit diagnostic instrument (CDI) was used in the study. The development and validation of CDI was guided by Treagust's (1988) procedures. It included defining the content (Lin, 2006), obtaining information about students' conceptions (Chiu & Lin, 2005), and developing the diagnostic instrument (Lin, 2006). Two schoolteachers and two science education professors with physics backgrounds validated the CDI. The content or applications were reported in several articles (Lin, 2008; Lin & Chiu, 2009; Lin & Wu, 2011, 2013). The Cronbach's α for the Grade 3 students was .59, and the test-retest reliability was .78 (Lin, 2008; Lin & Chiu, 2009). CDI consisted of many items, but some items were not appropriate for a web-based instrument (e.g., drawing items). Therefore, this study only selected multiple-choice questions and two-tier questions from the original CDI and presented them via the WMMD system (Wang, Chiu, Lin, & Chou, 2013) to collect students' (student version) and the ETs', PTs' (teacher version) data for reasonably large samples. The student version requires students to provide their *responses* and *confidence to answers* for each question. Since this study was interested in estimating students' pre-existing conceptions prior to instruction about electric circuits, the teacher version requires the teachers' *responses* and *confidence to answers* and their *predictions* of the most predominant *responses* among an elementary school student population who had not received relevant instruction about electricity (i.e. Grade 3 students, sample items in Appendix). It was assumed that teachers' instructional design and planning should be aligned closely with students' predominant responses that allow teachers to develop challenges for the pre-existing conceptions and experiences that might help the students to reconstruct their understandings of the ideas. Therefore, the teachers' ability to predict students' preconceptions was used as an indicator of their PCK. The prediction part of the CDI was validated by two science education professors with physics backgrounds and has been

Table 1. The format and brief description of item content

Format	Brief description of item content	Item code	Context
Multiple-choice questions	Closeness and bipolar circuit elements	M1	Simple circuit
		M2	Series circuit
Two-tier questions	Current model, brightness of bulbs, and energy in a series circuit Ohm's Law	T1	Closed circuit
		T2	Open circuit
		T3	Correlation between voltage and current
		T4	Correlation between resistance and current

reported elsewhere (Lin, 2016b). The internal consistency of the CDI for students was $\alpha = .62$ (Lin, 2016b), and for the inservice and the preservice teachers was $\alpha = .61$. Although these values are just acceptable, low internal consistency is expected for diagnostic instruments. The reason is that students' alternative conceptions are usually inconsistent and fragmented thereby not affording the same level of internal consistency obtained from more well-informed respondents with stable conceptual networks (Bretz & McClary, 2015).

CDI Responses

This study adopted multiple-choice questions and two-tier questions to diagnose the participants' alternative conceptions and CK. Traditional multiple-choice questions (i.e., tick all responses that apply) allowed participants to demonstrate their understanding about whether a bulb or bulbs would light in a simple or a series circuit, while the two-tier questions provided more information on their explanations about other electric circuit concepts (Table 1). Except for scientific response, all of the responses were classical alternative conceptions as recommended in the large body of literature.

Confidence

The respondent's *confidence associated with each answer* was measured in the form of a 5-point Likert scale (5 = high confidence ... 1 = low confidence). The test-retest reliability of the students' confidence rating in their answers was .90, and the criterion-related validity of the confidence to answers illustrated by the correlation between these measures was high ($r = .89$) (Lin & Wu, 2013). These results implied participants' confidence rating is an appropriate predictor of their conceptual understanding related to an item.

Data Analysis

Three analyses were conducted in the study: the percentage of ETs, PTs, and student responses for each question; the ETs' and PTs' confidence of each response; and the ETs' and PTs' prediction scores. The first two analyses provided a description about electric circuits as an indicator of their CK and the teachers' confidence in their response that allows categorisation of the responses. The third analysis explored the alignment between teachers'

predictions about students' conceptions and the students' actual conceptions as an indicator of the teachers' PCK.

CDI Responses

The multiple-choice questions required an understanding of *closeness* and *bipolar circuit elements*. Participants' responses were categorized as (a) with understanding of closeness and bipolar circuit elements, (b) with understanding of closeness but without bipolar circuit elements, (c) with understanding of bipolar circuit elements but without closeness, (d) without understanding of both closeness and bipolar circuit elements, and (e) with understanding of closeness but ignoring bipolar circuit elements. Students' responses in this category showed only one bulb would light in a closed series circuit.

Interpreting the responses to the two-tier questions reflected the participants' responses for both the first-tier and second-tier questions. Peterson, Treagust, and Garnett (1989) suggested that the percentage of student responses >20% for the non-scientific options be defined as *typical alternative responses* that teachers should consider carefully. However, 20% is an extremely large percentage for teachers and for teacher educators concerned about teachers' CK and about avoiding teachers misleading students' conceptions. The ETs' and PTs' scores in each question were compared by using an independent *t*-test to explore the similarities and differences between the two groups of teachers' CK.

Confidence

The participants who chose 5 points in the Likert scale were scored 5 marks, 4 points were scored 4 marks, and so on. We calculated the average scores of their confidence, which was associated with each response type. There were several responses in an item. Caleon and Subramaniam (2010) suggested that if the averages of the confidence responses were >3 (median), alternative responses would be categorized as *alternative conceptions* and scientific responses would be classified as *truly understanding*. Conversely, if the averages were ≤3, alternative responses would be categorized as *deficient knowledge* and scientific responses would be classified as *guessing*.

Prediction Scores

Predicting raw scores were calculated for the ETs' and the PTs' prediction ability of students' preconceptions. Each teacher had a predicting raw score for each question. Teachers who accurately predicted students' most frequent response (rank 1) were scored 4 points, those who predicted students' second most frequent response (rank 2) were scored 3 points, and so on. Each question ranged from five to seven possible responses. Therefore, responses that were ranked more than or equal to fifth place (the minimum of the responses in each question) were scored 0, which were rare and trivial. The sum of the scores in each prediction multiplied by its percentage for each question was calculated. If 50% of teachers predicted accurately, the prediction score was 2 (4 points × 50%). Finally, the teachers' predicting raw scores were converted into T-scores (standard score) for the distributions of the ETs' and PTs'

predictions, which were different. The teachers' T-scores were averaged to obtain the prediction score of each question. Comparison of the ETs' and PTs' prediction scores was conducted by using independent *t*-test to explore any differences between the two groups of teachers' insights and abilities of predicting students' preconceptions.

RESULTS

The results are reported in two sections that align with the research questions. The first section presents the ETs' and the PTs' CK, including their scientific understandings, alternative conceptions, guesses and deficient knowledge, and the inferential statistical results regarding the differences between the ETs' and the PTs' CK. The second section presents the ETs' and PTs' predictions of the students' performance and the inferential statistical results regarding the differences between the ETs' and the PTs' topic-specific PCK.

RQ#1: Experienced and Preservice Teachers' Content Knowledge of Electric Circuits

The ETs' and PTs' responses and their confidence in answering questions in the CDI are summarized in **Table 2**. The distributions of the responses are described below.

Closeness and Bipolar Circuit Elements: Simple and Series Circuit Contexts

The multiple-choice questions required the participants to infer which of the bulbs would light in a *simple* (M1) or *series* (M2) circuit (Appendix). For the category *truly understanding* in the context of M1, the ETs' proportion and the confidence level (94.7%, 4.8) were higher than the PTs' proportion and confidence level (76.5%, 4.2). However, the proportion and confidence of these two groups dropped in the M2 context (ETs: 84.2%, 4.5; PTs: 24.7%, 3.6); but the differences favouring the ETs were greater. This pattern indicated that the difficulty and complexity of a series circuit is more than for a simple circuit.

The category of alternative conceptions *without the understanding of bipolar circuit elements* was the only alternative conception found for ETs and PTs in both the M1 (ETs: 5.3%, 4.5; PTs: 22.4%, 3.3) and the M2 (ETs: 5.3%, 3.5; PTs: 63.5%, 3.2) contexts. Although only a few ETs chose this response, this was a typical alternative conception (percentage > 20%) for the PTs in the M1 and M2 contexts. Furthermore, the proportions of the ETs (10.5%, 4.5) and the PTs (10.6%, 2.8) *with understanding of closeness but ignoring bipolar circuit elements* were similar and categorized as *deficient knowledge*. The other concept that was categorized as *deficient knowledge* was *without understanding of both closeness and bipolar circuit elements* in the M1 and M2 contexts for the PTs. There was no area categorized as *guessing* in these two contexts.

Current Model, Brightness of Bulbs, and Energy in a Series Circuit: Closed and Open Circuit Contexts

The T1 and T2 questions were two-tier questions that required the understanding of current intensity and bulb brightness in *closed* (T1) and *open* (T2) circuit contexts. The ETs

Table 2. The ETs' and PTs' performance and confidence in answering questions in the CDI

Brief description of the responses	ETs (N = 76)		PTs (N = 85)		t	
	%	mean	%	mean		
	M1	With understanding of closeness and bipolar circuit elements.*	94.7^t	4.8		76.5^t
	Without understanding of bipolar circuit elements.	5.3 ^a	4.5	22.4^a	3.3	
	Without understanding of both closeness and bipolar circuit elements.	0	0	1.2 ^d	2.00	
	Without understanding of closeness.	0	0	0	0	
M2	With understanding of closeness and bipolar circuit elements.*	84.2^t	4.5	24.7^t	3.6	5.432***
	Without understanding of bipolar circuit elements.	5.3 ^a	3.5	63.5^a	3.2	
	Without understanding of both closeness and bipolar circuit elements.	0	0	1.2 ^d	2.0	
	Without understanding of closeness.	0	0	0	0	
	With understanding of closeness but ignoring bipolar circuit elements.	10.5 ^a	4.5	10.6 ^d	2.8	
T1	Attenuation model.	9.2 ^a	4.1	15.3 ^d	2.9	3.421**
	Crossing-currents model.	3.9 ^a	4.3	3.5 ^d	2.7	
	Bulbs have electricity themselves model.	1.3 ^a	5.0	1.2 ^d	3.0	
	Sharing current model.	6.6 ^a	4.0	30.6^a	3.4	
	Bipolar model; the bulbs absorb currents.	1.3 ^d	3.0	1.2 ^d	3.0	
	Bipolar model; the current is not consumed.	0	0	2.4 ^d	2.5	
	Scientific models.*	77.6^t	4.2	45.9^t	3.2	
T2	There is no current because of an open circuit.*	96.1^t	4.9	87.1^t	4.1	2.365*
	The direction of current is correct, and it flows to the open circuit point where it stops; current flows through the bulbs and they shine.	0	0	2.4 ^d	2.5	
	Current starts from the two poles of the battery and stops at the open circuit point; current flows through the bulbs and they shine.	0	0	2.4 ^a	4.5	
	Current flows like alternating current, and it stops until flowing to the open circuit point.	2.6 ^a	5.0	2.4 ^d	3.0	
	Current stops until it flows to the open circuit point; it is not a route, so the bulbs cannot shine.	1.3 ^a	4.0	5.9 ^a	3.8	
T3	The size of the battery affects the brightness of the bulbs and the current intensity.	5.3 ^a	4.3	4.7 ^d	2.8	.460
	Voltage magnitude affects the current intensity and the brightness of bulbs.*	85.5^t	4.6	81.2^t	3.8	
	The thickness of wires affects the current intensity.	1.3 ^a	5.0	4.7 ^a	3.3	
	The size of the battery affects the time of use and the current intensity, but it does not affect the brightness of bulbs.	7.9 ^a	4.5	9.4 ^d	3.0	
T4	The length of wires affects the current intensity.	1.3 ^d	2.0	8.2 ^d	2.3	2.090*
	Bulbs consume current.	9.2 ^a	3.9	15.3 ^d	2.7	
	The amount of wires affects the current intensity.	44.7^a	4.0	45.9^a	3.3	
	Bulbs share current equally.	3.9 ^a	4.3	12.9 ^a	3.4	
	The amount of bulbs is inversely proportional to the current intensity.*	40.8^t	4.7	17.6 ^g	2.8	

Note 1: * correct answers

2: The bold italics means the percentage of this response > 20%, (typical response).

3: "t" = truly understanding; "g" = guessing; "a" = alternative response; "d" = deficient.

demonstrated a *scientific model* (77.6%, 4.2) about the T1 context that was greater and more confident than the PTs (45.9%, 3.2). This pattern was also true for the T2 context (ETs: 96.1%, 4.9; PTs: 87.1%, 4.1).

Among the rest of the unscientific responses, most of the ETs' answers were categorized as *alternative conceptions* whereas the PTs' answers mainly belonged to the *deficient knowledge category*, for example, the *attenuation model* (ETs: 9.2%, 4.1; PTs: 15.3%, 2.9). The only unscientific response that the PTs held belonged to the alternative conception category was the *sharing current model* (30.6%, 3.4), which is a typical alternative conception that should receive more attention.

Ohm's Law: Correlations between Voltage and Current and between Resistance and Current Contexts

The *voltage-current* question (T3) required the participants to infer which of the batteries (i.e., larger or smaller one) would make the bulb brighter; the *resistance-current* question (T4) required the understanding of current intensity differences between a simple and a series circuit. Many of the ETs (85.5%, 4.6) and the PTs (81.2%, 3.8) in the T3 context expressed the scientific response that *voltage magnitude affects the current intensity and the brightness of bulbs*; the ETs were more confident than the PTs. However, both the ETs and PTs showed low correctness in the T4 context; the ETs (40.8%, 4.7) who chose the scientific response that *the amount of bulbs was inversely proportional to the current intensity* was much higher than the PTs (17.6%, 2.8). Furthermore, the ETs' performance was categorized as *truly understanding* whereas the PTs' performance was simply *guessing* because of the difference in confidence levels.

Among the rest of the unscientific responses, all of the ETs' answers in the T3 context belonged to *alternative conceptions* whereas the PTs' responses mainly belonged to *deficient knowledge*, for example, the response that *the size of the battery affected the time of use and the current intensity, but it did not affect the brightness of bulbs* (ETs: 7.9%, 4.5; PTs: 9.4%, 3.0). Both the ETs (44.7%, 4.0) and PTs (45.9%, 3.3) in the T4 context showed a high proportion for *the amount of wires affected the current intensity* response; their answers were classified as typical *alternative conceptions* that should not be overlooked. Finally, most of the ETs' answers about *bulbs consumed current* belonged to *alternative conceptions* whereas the PTs' answers mainly belonged to *deficient knowledge* (ETs: 9.2%, 3.9; PTs: 15.3%, 2.7).

Except for T3 responses, the *t*-tests of the differences revealed that the ETs' CK of electric circuits was significantly ($p < .05$) better than the PTs (**Table 2**). The ETs had a high percentage of *truly understanding* and fewer *alternative conceptions* with negligible *guessing* and *deficient knowledge*.

Table 3. The ETs' and PTs' prediction of students' responses in the CDI, T score of their predictions, and the result of the independent t test of their prediction scores

Brief description of the responses		Students' performance (N=438)	Prediction of ETs (N=76)	Prediction of PTs (N=85)	T score of ETs' vs. PTs' predictions	t
M1	With understanding of closeness and bipolar circuit elements.*	45.2	34.2	35.3	53.7	-0.468
	Without understanding of bipolar circuit elements.	41.3	60.5	62.4	vs. 54.0	
	Without understanding of both closeness and bipolar circuit elements.	11.6	5.3	2.4		
	Without understanding of closeness.	1.8	0.0	0.0		
M2	With understanding of closeness and bipolar circuit elements.*	37.7	21.1	25.9	50.3	-1.102
	Without understanding of bipolar circuit elements.	30.6	60.5	56.5	vs. 50.4	
	Without understanding of both closeness and bipolar circuit elements.	26.7	7.9	5.9		
	Without understanding of closeness.	2.7	1.3	0.0		
T1	With understanding of closeness but ignoring bipolar circuit elements.	2.3	9.2	11.8		
	Attenuation model.	31.7	55.3	34.1	48.9	2.681**
	Crossing-currents model.	16.9	5.3	2.4	vs. 43.9	
	Bulbs have electricity themselves model.	15.1	2.6	5.9		
	Sharing current model.	12.3	22.4	41.2		
	Bipolar model; the bulbs absorb currents.	11.4	2.6	2.4		
	Bipolar model; the current is not consumed.	7.8	1.3	3.5		
Scientific models.*	2.7	10.5	10.6			
T2	There is no current because of an open circuit.*	30.8	30.3	36.5	43.8	-1.145
	The direction of current is correct, and it flows to the open circuit point where it stops; current flows through the bulbs and they shine.	24.4	18.4	20.0	vs. 46.1	
	Current starts from the two poles of the battery and stops at the open circuit point; current flows through the bulbs and they shine.	18.3	5.3	7.1		
	Current flows like alternating current, and it stops until flowing to the open circuit point.	16.4	7.9	5.9		
	Current stops until it flows to the open circuit point; it is not a route, so the bulbs cannot shine.	9.6	38.2	30.6		
T3	The size of the battery affects the brightness of the bulbs and the current intensity.	56.2	92.1	78.8	58.0	2.073*
	Voltage magnitude affects the current intensity and the brightness of bulbs.*	19.9	5.3	11.8	vs. 56.4	
	The thickness of wires affects the current intensity.	14.6	0.0	5.9		
	The size of the battery affects the time of use and the current intensity, but it does not affect the brightness of bulbs.	9.4	2.6	3.5		
T4	The length of wires affects the current intensity.	46.3	15.8	20.0	46.6	-1.030
	Bulbs consume current.	23.1	38.2	37.6	vs. 48.0	
	The amount of wires affects the current intensity.	13.7	13.2	23.5		
	Bulbs share current equally.	8.9	28.9	11.8		
	The amount of bulbs is inversely proportional to the current intensity.*	6.2	3.9	7.1		

Note: 1. Students' missing data is not included, so the sum of students' performance may not equal to 100%
 2. The sequence of the brief description of the responses was based on the proportion of students' performance.
 3. The bold underline means the predominate prediction.

RQ#2: Experienced and Preservice Teachers' Predictions of Students' Preconceptions

Table 3 shows students' performance, the ETs' and PTs' predictions of student responses in the CDI, the T-score of their predictions, and the results of the independent *t*-test of their prediction scores. The highest level of student responses was placed first in the table to make reading easier. This section demonstrates the comparison of PCK (prediction of students' preconceptions as indicator) between the ETs and PTs. According to the findings, the relationships among PCK, teaching experience, and CK will be explored more fully in the conclusion and discussion section.

Closeness and Bipolar Circuit Elements: Simple Circuit and Series Circuit Contexts

The rank orders of the students' responses for the M1 question were first (rank 1) the correct answer: *with understanding of closeness and bipolar circuit elements* (45.2%) and second (rank 2) was *without understanding of bipolar circuit elements* (41.3%). However, 60.5% of the ETs and 62.4% of the PTs predicted the second-ranked response would be the students' predominant answer while 34.2% of the ETs and 35.3% of the PTs correctly predicted the students' predominant answer (rank 1). The ETs' and PTs' prediction pattern for the M2 context was similar to the M1 context where 60.5% of the ETs and 56.5% of the PTs chose the second-ranked student response *without understanding of bipolar circuit elements* as the students' predominant answer; only 21.1% of the ETs and 25.9% of the PTs predicted successfully the students' the most predominant response (rank 1) as their correct answer (37.7%).

The results show that most ETs and PTs did not realize that a sizeable minority of students, without formal instruction about electric circuits, would have a correct conception as their predominant answer. However, the top two ETs' and PTs' predictions corresponded with the first- and second-ranked student responses; both of the ETs' and PTs' prediction scores in M1 and M2 contexts were >50%. Comparison of ETs' and PTs' prediction scores revealed there was no significant ($p > .05$) difference between the ETs' and PTs' prediction scores for M1 ($t(159) = -.468, p = .640$) and M2 ($t(159) = -.102, p = .919$).

Current Model, Brightness of Bulbs, and Energy in a Series Circuit: Closed and Open Circuit Contexts

The most predominant student response in the T1 context was the *attenuation model* (31.7%), and the second most predominant response was the *crossing-currents model* (16.9%). More than half (55.3%) of the ETs, which represented the highest percentage among their answers, accurately predicted the students' rank 1 response. However, 40.2% of the PTs predicted the *sharing current model*, which only 12.3% of the students chose as their predominant response. The independent *t*-test showed a significant difference between the ETs' and PTs' prediction scores in this question ($t(159) = 2.681, p = .008$), revealing that the ETs' ability to predict students' answers was significantly better than the PTs' prediction abilities in the T1 context.

The most predominant student response in the T2 context was the scientific one that *there was no current because of an open circuit* (30.8%), and the second most predominant response was *the direction of current is correct, and it stops until it flows to the open circuit point; current flows through the bulbs and they shine* (24.4%). However, 38.2% of the ETs and 30.6% of the PTs predicted the response that *currents stopped until it flowed to the open circuit point; it was not a route, so the bulbs could not light* as the most predominant student response whereas only 9.6% of the students actually made this response. Furthermore, 30.3% of the ETs and 36.5% of the PTs correctly chose the scientific response as the students' predominant response. This result shows that the majority of the ETs and the PTs could not accurately predict the students' predominant response in the T2 context; instead, many of them predicted the very infrequent response among the students. Therefore, their prediction scores were 43.8 for ETs and 46.1 for PTs. The independent *t*-test showed no significant difference between ETs' and PTs' prediction scores ($t(159) = -1.145, p = .254$).

Ohm's Law: Correlations between Voltage and Current and between Resistance and Current Contexts

The students' most predominant response in the T3 context was *the size of the battery affected the brightness of the bulbs and the current intensity* (56.2%), and 92.1% of the ETs and 78.6% of the PTs correctly predicted this response. The ETs' and the PTs' prediction scores were 58.0 and 56.4, respectively, which indicates that both groups had highly accurate predictions for this item. However, the independent *t*-test revealed a significant difference between these groups ($t(150.732) = 2.073, p = .040$), favouring the ETs over the PTs.

The most predominant student response in the T4 context was *the length of wires affected the current intensity* (46.3%), and the second most predominant response was *bulbs consumed currents* (23.1%). However, only 15.8% of the ETs and 20.2% of the PTs correctly predicted the students' predominant answer while 38.2% of the ETs and 37.6% of the PTs predicted the second most predominant response. This indicates that many ETs and PTs could not predict students' preconceptions accurately for this question. The ETs' and PTs' prediction scores were 46.6 and 48.0. The independent *t*-tests revealed no significant difference between the means of these two groups' prediction scores ($t(159) = -1.030, p = .305$).

CONCLUSION AND DISCUSSION

Experienced Teachers Possess More Acceptable CK with Higher Confidence than Preservice Teachers

Teachers' CK is important for confidence building (Pardhan & Bano, 2001). Overall and as expected, the ETs possessed better CK with higher confidence than did the PTs. This result not only implies the lack of appropriate and applicable knowledge of PTs but also the weaker competency of their science teaching. One explanation is that the ETs have strengthened their science CK during their science teaching experiences and science education graduate

programs, lesson preparation, and classroom teaching. An alternative explanation is that the greater proportion of science majors in the ETs than the PTs accounted for the CK difference.

Teacher Educators Should Express Intention and Pay Attention to Teachers' Alternative Conceptions

The measurement of response confidence helped identify the participants' real alternative conceptions (Aithor, 2016; Caleon & Subramaniam, 2010; Kanli, 2014; Kirbulut, & Geban, 2014). The ETs and the PTs shared the same typical alternative conception about Ohm's law, that is, *the amount of wires affects the current intensity*. Furthermore, PTs held three typical alternative conceptions that teacher educators should afford careful concern within the relevant context of teaching and learning these ideas during science education courses: *without understanding of bipolar circuit elements in simple and series circuit contexts*, *using sharing current model* to explain the brightness of bulbs, and *energy in a series circuit*. A further comparison of students' responses about *sharing current model* and *the amount of wires affects the current intensity* indicated that they were not these Grade 3 students' typical alternative conceptions. However, these PTs' typical alternative conceptions have high potential to mislead or reinforce students' misunderstandings in the process of science teaching.

No Statistical Difference in Two-thirds of Test Items between the Experienced and Preservice Teachers' Predictions of Students' Preconceptions

Review of the ETs' and PTs' ability to predict students' preconceptions shows that both groups of teachers could not correctly predict the predominant responses students held; therefore, their PCK about electric circuits (knowing students' prior knowledge) was not significantly different. There was no statistical difference between the ETs' and PTs' prediction ability of the students' preconceptions about electric circuits, except for the T1 and T3 contexts. This result supports previous studies that claimed teachers are insensitive to students' preconceptions (Lin, 2016b; Lin & Chiu, 2010; Chi et al., 2004; Liang et al., 2011), but this study goes further to show the insensitivity is quite similar between ETs and PTs and does not appear to change with teaching experience and advanced science education study.

Experienced and Preservice Teachers' Learning Experiences Might be the Major Source on Which to Predict Students' Preconceptions

It was expected that the ETs possessed better pedagogical awareness and could more accurately predict students' preconceptions because they have more authentic opportunities and clinical experiences to detect the dynamic nature of students' conceptions. Furthermore, increased science and graduate science education studies did not appear to enhance their learning about PCK and students' ideas about specific science topics. However, the data indicated both ETs' and PTs' predictions of students' performance were mainly *the primary incorrect answer of their group*. For example, in M1, the ETs' and PTs' predominant response was *with understanding of closeness and bipolar circuit elements* (scientific explanation) and their second most predominant response was *without understanding of bipolar circuit elements*. Both

groups' predictions of the students' performance were mainly their second most predominant response. Furthermore in the T1 context, the ETs' and PTs' most predominant response was the *scientific model*; the ETs' second most predominant response was *attenuation model* and the PTs' was *sharing current model*. The ETs' predominant prediction of the students' performance was *attenuation model* while the PTs' predominant prediction was *sharing current model*. This pattern based on the teachers' predominant conceptions is similar to one-to-one tutoring research (Chi et al., 2004; Herppich et al., 2013). However, this study also found that this pattern failed when (a) the percentage of teachers' scientific response was high and their alternative responses were evenly distributed (e.g., ETs' and PTs' prediction in T2) or (b) most teachers held *incorrect answer* (e.g., ETs' and PTs' predictions in T4) for the difficulty in being aware of their own main type of incorrect conceptions. This pattern appears to show how the interactions of teachers' CK, prior learning experiences, and their predictions of students' preconceptions might be related.

IMPLICATIONS

The low quality of PTs' CK (i.e., high proportion of alternative conceptions, deficient knowledge, low confidence) implies a need to establish qualifications specific for elementary science teachers based on the actual science content and difficult-to-learn topics in the curriculum. Both inservice and preservice teachers should be aware of their own alternative conceptions. A web-based diagnostic system with self-confidence rating, such as the WMMD (Wang, Chiu, Lin, & Chou, 2013), could be established to assist science teachers in self-examination of their conceptual understanding and be more aware of their CK about curriculum-based science topics. Such formative assessment information might help them plan, design, and enact more effective conceptual change lessons appropriate to their target students.

Unlike the more rapid cultivation process of teachers' CK, transforming teachers' CK into PCK and applying these knowledge resources to professional practice is a recursive and dynamic struggle. Our research results suggest that – even though the ETs in this study had reasonable teaching experience with high motivation, abundant educational resources, and well-developed science education backgrounds to be classified as high-quality science teachers – their comprehension of students' preconceptions was still insufficient and that it might need to be fostered during ongoing professional learning. Furthermore, providing authentic opportunities and clinical experiences appeared to be insufficient for teachers to improve their PCK (Schneider & Plasman, 2011). The critical point might be that most teachers in Taiwan still use knowledge-telling strategies in classrooms rather than knowledge-constructing strategies. The knowledge-telling approach provides little opportunity to elicit and use students' conceptions and no strategy to monitor students' conceptual evolution. Although the importance of teachers' CK and PCK has been generally acknowledged (Duit & Treagust, 2012), more constructivist professional development strategies centred on students' pre-existing conceptions should be adopted to help inservice and preservice teachers to be

involved in reflective practice and become familiar with constructivist principles applicable to students' science learning.

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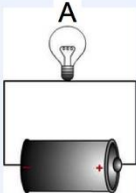
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APPENDICES

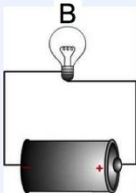
Appendix 1

www.iranibow.net/LimeSurvey/admin/admin.php?action=previewquestion&sid=86442&qid=801

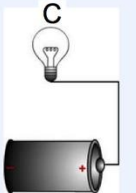
When the battery, the wire, and the bulb were connected as follows, which of the bulbs will shine?



A




B




C

tick all that apply

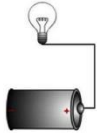
- 1. Bulb A will shine
- 2. Bulb B will shine
- 3. Bulb C will shine



A

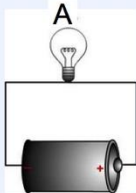


B

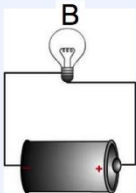


C

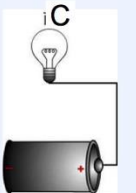
When the battery, the wire, and the bulb were connected as follows, which of the bulbs will shine? (Please make a prediction of students' dominant answer in this question.)



A




B




C

tick all that apply

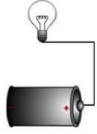
- 1. Bulb A will shine
- 2. Bulb B will shine
- 3. Bulb C will shine



A



B



C

<http://iserjournals.com/journals/eurasia>