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Development of an Instrument to Assess University Students' Perceptions of Their Science Instructors' TPACK

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Abstract: While university science teachers' technological pedagogical and content knowledge (TPACK) is crucial for effective teaching, college-oriented, student-perceived measurements are still lacking. Hence, this research was conducted to make up for such a deficiency. We reviewed the literature and constructed a theoretical framework, which includes the conceptualization of our proposed five-component TPACK structure. The student-perceived TPACK instrument was developed and validated in a university context. Our factor analysis of the 33-item TPACK instrument revealed a four-factor structure, which is different from our original five-component framework. The TPACK instrument is content neutral in the sense that there are no items that references content-specific ideas, knowledge, or practice. The uses of qualitative and quantitative data make the instrument adaptive and flexible, enabling us to capture college science instructors' TPACK and track their knowledge development. The research implications of this study are provided along with suggestions.

Key words: TPACK, instrument, science instructors, university students' perceptions

1. Introduction

In the last decade, there has been a prioritized educational policy in Taiwan that aims to leverage "teaching excellence" in higher education (Jang Guan & Hsieh, 2009). Accompanying this trend, Professional Development or Teaching Excellence Centers have been established in colleges and universities throughout Taiwan. These centers provide faculty in-service training, teaching consultation, and technology orientation. The underlying rationale is that college instructors play a key role in ensuring the quality of higher education (Jang, 2011). Furthermore, unlike K-12 schoolteachers who have received formal teacher education training, college instructors need to keep elaborating their teaching methods and strategies while enriching their area of expertise.

The above rationale sharply contrasts the widespread misconception that college instructors feel at ease with teaching because most faculty members have earned a doctorate and so presumably achieve a certain level of specialty. The unfortunate truth is that college instructors are among the "at-risk" groups for teaching. Abell, Rogers, Hanuscin, Lee and Gagnon (2009) pointed out that novice college instructors are especially susceptible to teaching difficulties because most doctoral programs do not provide any pedagogical training or practicum

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opportunities as commonly seen in teacher education programs. Similarly, Jaskyte, Taylor and Smariga (2009) stated that the majority of doctoral programs emphasize research skills but ignore teaching methods and curriculum design. Consequently, many novice college instructors do not know how to transform their expertise into teachable formats. In order to investigate factors affecting teaching efficacy and teaching difficulties, scholars have recommended defining teacher knowledge. As part of this trend, Shulman's (1986, 1987) pedagogical content knowledge (PCK) has been described as a knowledge base necessary for effective teaching in many educational reform documents (AAAS, 1993; NRC, 1996).

On the other hand, the advancement and prevalence of technology (e.g., computers, the Internet, and mobile devices) has changed every facet of life, including education. National standards such as NETS-T 2000 and 2008 have been enacted by the International Society for Technology in Education for schoolteachers as guidelines for teaching with technology. NETS-T 2000 specifically identified six categories of teacher capacity, including: (1) technology operations and concepts; (2) planning and designing learning environments and experiences; (3) teaching, learning, and curriculum; (4) assessment and evaluation; (5) productivity and professional practice; (6) social, ethical, legal, and human issues (ISTE, 2002). In contrast to this type of "technology movement" in education, Shulman's PCK seems insufficient to capture the full range of teacher knowledge. As will be detailed later, the notion of PCK has been extended by Niess (2005), Kohler and Mishra (2005) into technological pedagogical content knowledge (TPCK), which represents the amalgam of technology, pedagogy, and content knowledge of teachers. Later, Thompson and Mishra (2007) proposed to rename it with the acronym TPACK (pronounced "tea pack") in order to highlight teacher knowledge as an integrated whole (like a Total Package). In that sense, knowledge of technology, pedagogy, and content are consolidated into a holistic knowledge system (Jang, 2010; Jang & Chen, 2010).

Although the notion of TPCK or TPACK has been gaining recognition and acceptance from educational researchers in recent years, research on assessment of teachers' TPACK is just beginning (Graham, Burgoyne, Cantrell, Smith, St. Clair & Harris, 2009; Schmidt, Baran, Thompson, Mishra, Koehler, & Shin, 2009). Several TPACK surveys have since been designed and those that have been validated through exploratory or confirmatory factor analyses with large sample respondents generally report difficulty with isolating all seven constructs (Archambault & Barnett, 2010; Chai, Koh, & Tsai, 2010; Jang & Tsai, 2012; Koh, Chai, & Tsai, 2010; Lee & Tsai, 2010). Upon reviewing TPACK-related questionnaires and surveys, we found that quality instruments that measure university teachers' TPACK are scarce. What is more, most existing TPACK questionnaires and surveys are designed for teachers' self-description while few have addressed students' perceptions of their teachers' knowledge.

According to Tuan, Chang, Wang and Treagust (2000), students' perceptions of teachers' knowledge may provide rich information about students' cognition and classroom processes. Tuan et al. also pointed out that students expect teachers to have strong content knowledge as well as expect teachers to use effective instructional methods. Such expectations infer that students were able to provide their opinions for the researchers as a reflection to discern whether teachers' PCK was good or bad. Therefore, we contend that, although student perceptions may not be exactly the same as teacher's self-perceptions, it provides a relatively objective (via surveying multiple students) account and alternative view of instructors' practices as a proxy for the latent trait, TPACK. Another benefit of student-perceived instruments, from a pragmatic point of view, is that large samples can be easily collected for research. Accordingly, the main purpose of this study is to develop an instrument as a tool that assesses students' views of university science teachers' TPACK.

2. Theoretical Framework

2.1 From PCK to TPACK

The notion of pedagogical content knowledge (PCK) was originally introduced by Lee S. Shulman (1986) to argue against derogations/general misconceptions of the teaching profession and skewed state examinations of schoolteachers that focused merely on teaching content. Shulman, in recognition of the teaching profession, specified three categories of teacher knowledge: (1) subject matter knowledge, (2) PCK, and (3) curricular knowledge. Later, in his landmark article: "Knowledge and Teaching: Foundations of the New Reform," Shulman (1987) elaborated on the scope of PCK by classifying teacher knowledge into seven categories, of which the first three categories are content-related and the remaining four categories are pedagogically oriented (Van Driel, Verloop & de Vos, 1998). These seven categories are (1) content knowledge, (2) general pedagogical knowledge, (3) curriculum knowledge, (4) PCK, (5) knowledge of learner and their characteristics, (6) knowledge of educational contexts, and (7) knowledge of educational ends, purposes, and values, and their philosophy and historical grounds. Among the seven kinds of knowledge, PCK was deemed most important as it amalgamates and integrates the other six types of knowledge. Shulman (1987) described pedagogical content knowledge as "the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8). It is PCK that distinguishes teachers from content specialist and scholars in terms of the ability to teach.

Shulman's insights have inspired many researchers to examine teacher knowledge in various domains, as well as to further explore or modify conceptions under the umbrella of PCK (e.g., Barnett and Hodson, 2001; Cochran, King & De Ruiter, 1991; Geddis, Onslow, Beynon & Oesch, 1993; Grossman, 1990; Van Driel et al. 1998). Geddis et al. (1993) defined PCK as knowledge that plays a role in transforming subject matter into forms that are more accessible to students. In particular, the transformation of teacher knowledge is an intentional act in which teachers choose to reconstruct their understanding to fit a situation. Therefore, PCK can be expressed when teachers deal with the transformation of subject matter for a specific group of students in a specific classroom, and in this regard PCK is closely linked to teachers' actual teaching performances and student learning.

Grossman (1990) regarded PCK as knowledge of strategies and representations for teaching particular topics, and knowledge of students' understanding and misconceptions of these topics. Grossman specifically emphasized the interplay among three types of teacher knowledge: subject matter knowledge, general pedagogical knowledge, and contextual knowledge. Subject matter knowledge refers to teachers' understanding of facts, concepts, as well as syntactic and substantive structures of the content. General pedagogical knowledge includes knowledge of learners and learning, classroom management, and curriculum and instruction. Contextual knowledge represents teacher's knowledge of the immediate learning environments such as district, community, school and its properties as well as subcultures of students.

The overarching influence of constructivism also sheds lights on the definition of PCK. Cochran, King and De Ruiter (1991) argued that teacher knowledge is not static; instead, it is dynamic and shaped through teaching practice. They coined the term pedagogical content knowing (PCKg) to reflect the dynamic nature of teacher knowledge. Four components, namely knowledge of subject matter, knowledge of students, knowledge of environmental contexts, and knowledge of pedagogy were identified in Cochran, DeRuiter and King's (1993) definition: "the manner in which teachers relate their pedagogical knowledge to their subject matter knowledge in the school context, for the teaching of specific students" (p. 1).

Barnett and Hodson (2001) highlighted the pedagogical context knowledge of science teachers. Science teachers gradually cultivate themselves into the knowledge, belief, attitudes, and value systems of the community through social interactions. It is also through social interactions that science teachers create a repertoire of context-specific knowledge that helps them fit into the various "microworlds" associated with science education, teacher professionalism, science curriculum, and their particular school culture. In Barnett and Hodson's model, pedagogical content knowledge was positioned as a subcategory of pedagogical context knowledge, paralleling the other three subcategories: professional knowledge, academic and research knowledge, and classroom knowledge.

To date, several PCK-related conceptualizations have been presented; however, we do not intend to be exhaustive. Instead, we point out that "there is no universally accepted conceptualization of PCK" (van Driel, Verloop & de Vos, 1998, p. 677) due to its amorphous nature. Furthermore, as the world is constantly changing and impacting education, components that constitute codifiable teacher knowledge are subject to change. Nevertheless, van Driel et al. (1998) suggested that all scholars agree on Shulman's two knowledge components: (1) knowledge of representations of subject matter and (2) understanding of specific learning difficulties and student conceptions. Here, we also found that Shulman's other two knowledge components are more often cited: (3) subject matter knowledge and (4) knowledge of educational contexts. The above four components are fundamental and constitute the core of pedagogical content knowledge in this study.

2.2 The TPACK Conceptual Framework

In 2005, Kohler and Mishra proposed the TPACK framework, which contains seven elements or categories: (1) technology knowledge (TK), (2) content knowledge (CK), (3) pedagogical knowledge (PK), (4) pedagogical content knowledge (PCK), (5) technological content knowledge (TCK), (6) technological pedagogical knowledge (TPK), and (7) technological pedagogical content knowledge (TPCK). According to Mishera and Koehler (2006), and their colleagues, the TPACK framework was built on Shulman's PCK to include technological knowledge as situated within content and pedagogical knowledge in specific contexts (Mishera & Koehler, 2009; Schmidt et al., 2009). These contexts might include curriculum knowledge, teaching philosophy, student knowledge evaluation, etc. (Grossman, 1990; Shulman, 1987; Tamir, 1998). In this study, we used TPACK rather than the PCK construct to introduce a new instrument to measure a new aspect of teacher knowledge, because the TPACK framework not only expresses the importance of the original PCK and technology integration, but it also introduces the complex interrelationships among technology, pedagogy and content in a specific context.

Research on college instructors' TPACK is scant in comparison with that of research on pre-service or K-12 teachers. Previous attempts to measure TPACK included the work by Koehler and Mishra (2005), in which they developed survey items to capture the development of TPACK knowledge components among four faculty members and 13 students through learning by design initiative. Koehler and Mishra specifically devised TPACK questions for individuals and groups for comparison of results. However, the TPACK measure is short, containing only five individual items and nine group items. No reliability and validity data were reported. A more salient limitation is that the survey is specific to the course experience and thus hardly generalizable to other contents, contexts, and approaches (Schmidt et al., 2009).

Graham et al. (2009) designed another survey to measure TPACK confidence of elementary science teachers. The survey items were clearly stated and each was targeted on a specific task. Though the reliability was reported to be high in each of the four domains, the survey was not subjected to item analysis and factor analysis to establish its construct/factorial validity. Moreover, the instrument seemed to be technology-oriented because the four measured components (TK, TPK, TCK, and TPACK) were all associated with technology. Surprisingly, content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) were ignored in the instrument developed in the study by Graham et al. A more rigorously constructed instrument is found in the study of Schmidt et al. (2009), which aimed to assess the TPACK knowledge structure of pre-service teachers. The survey was subjected to factor and item analyses, as well as expert reviews for content validity. Reliability tests revealed acceptable-to-excellent results for the seven subscales. According to the authors, the instrument can help educators design longitudinal studies to assess pre-service teachers' development of TPACK.

Based on the instrument of Schmidt et al. (2009), Chai, Koh, and Tsai (2010) revised the instrument and addressed 889 pre-service teachers to investigate their perceptions of teachers' TPACK. They suggested a way of achieving a confirmatory factor model fit by omitting three intermediary knowledge constructs (PCK, TCK, and TPK). Although they were able to obtain a four-factor model with good fit indexes, this four-factor model (TK, CK, PK, and TPACK) may limit one's understanding of the intermediary stages of TPACK formation. Koh et al. (2010) suggested that careful consideration of the pedagogical approaches adopted may yield better factor analysis results. The analyses of Koh et al.'s study yielded 5 factors instead of seven factors. While the TK and CK factors were identified, items from TPK, TCK and TPACK were lumped together, while items from PK and PCK were put together. In addition, a fifth factor labeled "knowledge from critical reflection" was identified. Chai et al. (2011) further addressed the training of 834 pre-service teachers at a teachers' college in Singapore to qualify them as primary school teachers, and understood the relationships amongst the seven TPACK constructs during teachers' TPACK development process. The researchers were able to uncover five of the seven TPACK constructs which were a better model fit as compared with several extant studies of TPACK surveys. Nevertheless, we found that the above instruments were designed for pre-service teachers' self-descriptions while few have addressed university students' perceptions of their instructors' knowledge.

2.3 Two Research Gaps

Upon reviewing TPACK questionnaires and surveys, we found only a small number of quality instruments that measure university teachers' TPACK. Furthermore, many questionnaires are designed for pr-eservice or in-service teachers' self-descriptions of TPACK but few have addressed university students' perceptions of their teachers' knowledge, as mentioned earlier. In fact, empirical studies have shown that student perceptions are valuable in understanding teacher knowledge and actions in situ. For instance, students in Jang's (2011) research reported that a good instructor explains subject matter clearly, uses feedback to understand students' prior conceptions of the subject matter and learning difficulties, provides adaptable instructional strategies based on student feedback, and offers additional help to students. Jaskyte et al. (2009) described student ranking of innovative teacher behaviors (i.e., indices of teachers' PCK). Notably, the student ranking revealed in their study was quite different from that of the faculty, even though the two groups identified similar characteristics of innovative teaching. Jaskyte et al. suggested that views of both the instructor and student are important sources when examining teacher knowledge in classroom contexts.

Another point worth addressing is that the majority of questionnaires have been developed based on Koehler and Mishra's seven-component framework in which PCK has been "shriveled" into just one of seven components. While such design looks "theory-based' and aligns with the Venn diagram created by Koehler and Mishra, we contend that, to a certain extent, such design and categorization is trivialized, techno-centric, and deviates from the essence of the original PCK. Furthermore, Angeli and Valanides (2009) argued that the boundaries between some components of TPACK, for example, what they define as TCK, TPK and TPCK, are fuzzy, indicating a weakness in accurate knowledge categorization or discrimination, and, consequently, a lack of precision in the framework. Archambault and Barnett (2010) also revisited and explored the TPACK framework through the use of factor analysis to measure each of the areas described. While the framework is helpful from an organizational standpoint, however, it is difficult to split up each of the technology-related domains. Therefore, we built a new (fifth) component "Technology Integration and Application (TIA)", which includes all technology-related components (TK, TCK, TPK, and TPCK). The other components of TPACK, such as CK, PK, PCK and Contexts, are the four fundamental components (e.g., subject matter knowledge, knowledge of instructional representation and strategies, knowledge of students' understanding, and knowledge of educational contexts) which constitute the core of pedagogical content knowledge.

Based on above the review of the literature on TPACK, five main categories of teacher knowledge were identified to investigate dimensions of TPACK in this study, namely (1) Subject Matter Knowledge (SMK), (2) Instructional Representation and Strategies (IRS), (3) Instructional Objective and Context (IOC), (4) Knowledge of Students' Understanding (KSU), and (5) Technology Integration and Application (TIA).

3. Development of TPACK Instrument

3.1 Draft of Initial Items

We started drafting questionnaire items according to our proposed five-component TPACK framework. Seven items were placed under each category, with a total of 35 items, with reference to the consensus of our research team. The items were ranked on a 5-point Likert scale anchored by 1 (not at all true) to 5 (very true). In order to ensure its readability and comprehensibility, the draft questions were reviewed by college students to correct any ambiguity in narration. The items were then sent to two science education scholars and one educational technology specialist for content review.

3.2 Item Analysis

Upon modifying item descriptions according to feedback from experts, we launched a pilot study to assess the psychometric quality of the 35 items. A total of 317 college students in Taiwan participated in the pilot study. The participants were majoring in biology, physics, chemistry, and engineering. Comrey (1988) argued that "A sample size of 200 is reasonably good for ordinary factor-analytic work with 40 or fewer variables. More variables require larger samples (p. 758)". Another criterion was proposed by Gorsuch (1983), who maintained that the minimum sample size should be five times the number of survey items. According to the above criteria, the number of participants in this study was sufficient to validate the questionnaire.

We computed item-total (subscale) correlations to analyze each item. Results showed that item-total correlation ranged from .77 to .80 for SMK items, .79 to .86 for IRS, .80 to .91 for IOC, .70 to .84 for KSU, and .79 to .90 for TIA items, indicating good item quality. An exception was found in the KSU category wherein item 28 "My teacher's tests cannot help me realize my learning situation" failed to correlate significantly with the subscale score ($r < .30$). Judging from the low correlation and its likelihood to cause confusion (due to its inverse question format), we decided to eliminate item 28, reducing the total number of items to 34.

3.3 Factor Analysis

An exploratory factor analysis (using the principle component method with varimax rotation) was conducted to examine the dimensions of the 34 items (Field, 2009). The purposes for this were two-fold: to further verify the items within the questionnaire and to examine the factorial validity of the questionnaire. Four factors (eigenvalue > 1) emerged as a result, and cumulatively explained 72.2 % of the total variance. Table 1 shows the factor loading and items within each factor.

Table 1 Factor Structure of TPACK Instrument

Item No.	Factor Component			
	1 (SMK)	2 (TIA)	3 (IRS)	4 (KSU)
PQ03	.789			
PQ02	.786			
PQ01	.770			
PQ07	.763			
PQ04	.732			
PQ15	.658			
PQ06	.649			
PQ21	.628			
PQ05	.621			
PQ17	.620			
PQ31		.877		
PQ32		.864		
PQ33		.831		
PQ30		.813		
PQ29		.762		
PQ35		.728		
PQ34		.697		
PQ12			.825	
PQ14			.811	
PQ13			.703	
PQ19			.570	
PQ16			.546	
PQ11			.541	
PQ18			.529	
PQ10	.575		.510	
PQ09	.621		.498	
PQ08	.637		.480	
PQ25				.772
PQ23				.682
PQ27				.674
PQ22				.665
PQ24				.619
~~PQ20~~	~~.522~~	~~.299~~	~~.484~~	~~.363~~

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 6 iterations

We compared the items within the four factors with those in the original five dimensions. Generally, those in the original SMK, TIA, IRS, and KSU categories corresponded with factors one to four respectively. Therefore, we kept using SMK, TIA, IRS, and KSU as factor names (and we kept the original order of the dimensions: SMK → IRS→ KSU→ TIA for consistency). Nevertheless, items eight to ten, which were originally within the IRS category, had higher loadings on the SMK factor even though their loadings on IRS also exceeded .40. After re-examining the item content, we decided to keep the three items in the original IRS category.

Additionally, IOC items spread in both SMK and IRS factors. More specifically, item 15 "My teacher enables me to understand clearly the objectives of this course", item 17 "My teacher pays attention to students' reaction during class and adjusts his/her teaching attitude", and item 21 "My teacher's belief or value in teaching is active and aggressive" fell into the SMK factor. Considering that "goal, attitude, and value" are more relevant to the term "belief", and that there are no clear-cut and universally-accepted distinctions between knowledge and belief (Avraamidou & Zembal-Saul, 2010; Southerland, Sinatra, & Matthews, 2001), we decided to keep the three (belief-related) items in the SMK dimension. We will discuss this in more detail in the Discussion section.

The original IOC item 16 "My teacher provides an appropriate interaction or good atmosphere", item 18 "My teacher creates a classroom circumstance to promote my interest for learning", and item 19 "My teacher prepares some additional teaching materials" were relegated to the IRS factor. After a discussion with the research team, we determined that these items also represent strategies for teaching; in particular, items 16 and 18 are more relevant to classroom management strategies. Therefore, we kept the three items in the IRS factor, and we further included classroom management strategies into our IRS conceptual framework. Notably, item 20 "My teacher copes with our classroom context appropriately" had relatively even factor loadings across the four factors. Moreover, it was hard to sort this item into any factor. Thus, we decided to eliminate it, making the total number of items 33.

3.4 Reliability and Validity

Cronbach's Alpha was computed to assess the instrument's reliability. Results showed that all the four subscales as well as the total scale had very high internal consistency (> .902). As such, we decided to finalize our scale items without further modifications. The final version of the TPACK instrument contains 33 items in four dimensions: (1) Subject Matter Knowledge (SMK, 10 items), (2) Instructional Representations and Strategies (IRS, 10 items), (3) Knowledge of Students' Understanding (KSU, 6 items), and, (4) Technology Integration and Application (TIA, 7 items). The entire TPACK instrument is presented in Appendix A.

This TPACK instrument should bear satisfactory content and construct validity. First, we have gone through an intensive review of empirical studies and existing questionnaires in order to establish the theoretical grounds for our TPACK instrument. Furthermore, the items have been subjected to multiple revisions according to (1) student reviews of readability and clarity of narrations; (2) expert reviews of coverage and conceptual accuracy; (3) item analysis for screening poor items; and (4) factor analysis for re-evaluating dimensions of TPACK in a college context. Although the factor analysis result deviated slightly from our original five-dimension framework, we found that the new four dimensions captured even better Taiwanese university contexts, as will be explained in the Discussion section.

4. Discussion and Implications

The major contribution of this study includes the construction of theoretical bases and the development of an instrument for assessing university students' perceptions of their science instructors' TPACK. The use of survey helped us understand the overall teaching performance of the instructors from students' points of view and provided the instructors materials for teaching reflection. Furthermore, compared with traditional end-of-semester evaluations which only produces a few feedback and does not leave time for teaching improvement in the same class because the semester has ended (Jang, 2011), the design of this study facilitates the collection of many student opinions through open-ended questions and provides a diagnostic function to allow the instructors to make changes after a given period of teaching. In other words, the research design allows for reflective thinking as well as timely modifications (Clegg, Tan & Saeidi, 2002).

In essence, university instructors are the authority in the traditional classroom and can easily have self-centered thinking. Using the survey developed in this study, researchers can determine whether the instructors achieve the expected goals by understanding students' perceptions (Jang, 2011; Tuan, Chang, Wang & Treagust, 2000). Moreover, the instructors can gain more teaching and learning experiences by participating in investigations. The TPACK development of the instructors is evaluated according to the reflective opinions of all the students and is not restricted to a few observations or interview data (De Jong, Van Driel, & Verloop, 2005; Jang, 2010). However, surveys have some limitations. Quantitative presentation does not investigate factors behind instructors' development in depth, nor does it allow for assessment of content-specific details. The researchers may collect supplemental qualitative data in various ways, such as through interviews, observations, and the open-ended opinions of students, to cross-validate whether the instructors' TPACK have improved or not.

The TPACK instrument is content neutral in the sense that there are no items that references content-specific ideas, knowledge, or practice. In other words, the instrument is content-neutral for general science rather than content-specific to physics. Nevertheless, science instructors' TPACK emphasizes the specific science content (Clermont, Borko, & Krajcik, 1994; van Driel, Verloop, & de Vos, 1998), which is useful for describing teachers' knowledge of how science subject matter and specific units are transformed by the application of technology (Jimoyiannis, 2010). The fact that the TPACK is administered in the context of a specific classroom relevant to the instructor of that course provides a tacit appeal to the specific content associated with that specific classroom context. So although the instrument itself does not directly and explicitly measure content-specific aspects of TPACK, the content specificity is implied by virtue of the fact that it is implemented in situ. We believe that tacit uses of qualitative and quantitative data make the instrument adaptive and flexible, enabling us to capture college science instructors' TPACK and track their knowledge development.

Kolher and Mishra's TPACK framework has the potential to provide a strong foundation for technology integration research of science teachers' PCK (Graham, 2011). Such a framework focuses on three major areas of teaching, namely content, pedagogy, and technology and the relationship between these domains. However, it does not emphasize the important domains within the original PCK (Grossman, 1990; Schulman, 1987), namely Knowledge of Students' Understanding (KSU). The TPACK instrument developed in this study not only emphasizes core elements of PCK, such as SMK, IRS, and KSU dimensions, but it also includes TIA- all technology related components. This can help clarify the boundaries between TPK and TCK in practical teaching (Angeli & Valanides, 2009). Archambault and Barnett (2010), after intensive explorations and comparisons, only found one clear-cut factor: knowledge of technology. They concluded, "Although the TPACK framework is helpful from an organizational standpoint, the data from this study suggest that it faces the same problem as that of pedagogical content knowledge in that it is difficult to separate out each of the domains, calling into question their existence in practice (p. 1659)". Therefore, this TPACK instrument has its advantages in these respects.

Our factor analysis of the 33-item TPACK instrument revealed a four-factor structure, which is different from our original five-component framework. IOC dimension of this study has "disappeared" and its items are relegated into SMK and IRS categories. This result does not mean that knowledge of instructional objectives and context is non-existent or unimportant in higher education, but it does reflect the actual Taiwanese college contexts. In the IOC dimension, three items related to belief are included in the SMK category. From the theoretical view, Southerland, Sinatra, and Matthews (2001) stated, "distinctions between knowledge and belief, complex and confusing at the theoretical level, seem to become hopelessly blurred at the empirical level" (p. 348). In this study, "knowledge" refers to the intertwined nature of science and the interchange of subject matter knowledge and other types of knowledge, whereas "belief" represents how instructors teach science or students learn science. From the practical point of view, science instructors' subject matter knowledge should include the objectives of the course, and their active attitudes, values and beliefs about teaching, which are considered to affect real classroom practices (Avraamidou & Zembal-Saul, 2010). We, hence, kept SMK knowledge and beliefs together in recognition of the complexity of the ways in which the two concepts are connected, and the fact that the boundaries between them are blurred.

On the other hand, three other items related to classroom management are included in the IRS category. From the practical sense, unlike K-12 settings, classroom management and the creation of learning atmosphere are not treated as main issues in higher education. Instead, the cultivation of domain expertise and research ability receives much more emphasis in Taiwanese colleges and universities. This contextual specification has blurred the boundary between knowledge of context and other knowledge components (Kind, 2009), undermining the status of IOC as a distinct factor. As discussed earlier, knowledge of goals, and teacher belief have been mingled with college instructors' SMK and teachers' knowledge of classroom management and the ability to create interactive learning environments have been regarded as an integral part of IRS in higher education.

Several suggestions are proposed in the research process as a reference for revisions of future questionnaires. First, instructors or researchers should encourage students to answer the open-ended items in the questionnaire as an explanation of quantitative scores. Then, we plan to administer the survey periodically on novice college instructors and use the results to inform researchers of specific times or events when each knowledge domain is developed. This information will provide valuable insights into college science instructors' development of TPACK, as well as providing feedback on effective approaches that facilitate their TPACK development.

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Appendix A: The TPACK Instrument

Questionnaire on University Students' Perceptions of Science Instructor's TPACK

A. Subject Matter Knowledge (SMK)

1. I think my teacher knows the content he/she is teaching.
2. I think my teacher explains clearly the content of the subject.
3. I believe my teacher knows how theories or principles of the subject have been developed.
4. I think my teacher selects the appropriate content for students.
5. I believe my teacher knows the answers to questions that we ask about the subject.
6. I think my teacher explains the impact of subject matter on society.
7. I think my teacher knows the whole structure and direction of this subject matter.
8. I think my teacher makes me clearly understand objectives of this course.
9. I believe my teacher pays attention to students' reaction during class and adjusts his/her teaching attitude.
10. I think my teacher's belief or value in teaching is positive.

B. Instructional Representation & Strategies (IRS)

11. I think my teacher uses appropriate examples to explain concepts related to subject matter.
12. I think my teacher uses familiar analogies to explain concepts of subject matter.
13. I believe my teacher's teaching methods keep me interested in this subject.
14. I think my teacher provides opportunities for me to express my views during class.
15. I think my teacher uses demonstrations to help explaining the main concept.
16. I believe my teacher uses a variety of teaching approaches to transform subject matter into comprehensible knowledge.
17. I think my teacher adopts group discussion or cooperative learning.
18. I think my teacher provides an appropriate interaction or good atmosphere.
19. I think my teacher creates a classroom circumstance to promote my interest for learning.
20. I think my teacher prepares some additional teaching materials.

C. Knowledge of Students' Understanding (KSU)

21. I believe my teacher realizes students' prior knowledge before class.
22. I believe my teacher knows students' learning difficulties of subject before class.
23. I think my teacher's questions evaluate my understanding of a topic.
24. I think my teacher's assessment methods evaluate my understanding of the subject.
25. I think my teacher uses different approaches (questions, discussion, etc.) to find out whether I understand.
26. I believe my teacher's assignments facilitate my understanding of the subject.

D. Technology Integration & Application (TIA)

27. I think my teacher knows how to use multimedia (e.g. PowerPoint and animation, etc.) for teaching.
28. I believe my teacher knows how to use web technologies (e.g. teaching website, Blog, and distance learning) for teaching.
29. I believe my teacher is able to choose multimedia and web technologies which enhance his/her teaching for a specific course unit.
30. I think my teacher is able to use technology to enhance our understanding and learning of lessons.
31. I think my teacher is able to use technology to enrich the teaching content and materials.
32. I think my teacher is able to integrate content, technology, and teaching methods in his/her teaching.
33. I believe my teacher is able to choose diverse technologies and teaching methods for a specific course unit.

Comments:

In this course, if you have any learning difficulty or opinion, please describe it as follows.

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