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Exploring the structure of TPACK with video-embedded and discipline-focused assessments

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ABSTRACT

The appropriate selection and implementation of technology in instruction is made possible by teachers' Technological Pedagogical Content Knowledge (TPACK). The TPACK that inservice teachers develop is practitioner-based and can be continuously transformed with teaching experiences. In this study, we constructed video-embedded and discipline-focused questionnaires to measure science teachers' TPACK. Item sets were generic across four disciplines and designed to investigate teachers' TPACK at different levels of the cognitive process. Each questionnaire was embedded with three instructional clips in which preservice teachers demonstrated their previously-prepared lessons on selected topics in biology, chemistry, earth science, and physics. Through exploratory factor analysis, four factors (i.e., *evaluation*, *evaluation/synthesis*, *application/analysis*, and *knowledge/comprehension*) emerged from the data. The presumed hierarchical interrelationships among these cognitive processes were investigated through a path analysis. The findings indicated that teachers' TPACK at the *knowledge/comprehension* level made significant loadings to TPACK at higher levels, but this was not the case for *application/analysis*. The disconnect for *application/analysis* within the simple-to-complex cognitive process hierarchy suggests that it should be viewed as different from the other three constructs that incorporate more instructional reasoning. The designs for the questionnaire items and embedded instructional clips that were used to elicit teachers' practical knowledge are presented herein.

1. Introduction

Pedagogical content knowledge (PCK) refers to the knowledge construct that teachers develop for and in practice, within which knowledge of instructional representations and students' learning difficulties are the main constitutional elements that determine teachers' effectiveness (Shulman, 1986; van Driel, Verloop, & de Vos, 1998). Technological Pedagogical Content Knowledge (TPACK) is viewed as a strand of PCK, since technology can be used as a tool to assist teachers' instruction and students' learning (Angeli & Valanides, 2009; Mishra & Koehler, 2006). Disregarding whether representations are supported by technology, qualified teachers are expected to be equipped with a PCK that is blended with their factual and craft knowledge to support their content-generic and content-specific instruction.

Science is a subject that can greatly benefit from technology implementation. Technology-enhanced representations facilitate learners' visualization of micro-level and macro-level phenomena, while the use of multiple representations allows

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students to explore and consolidate their conceptualizations (Ainsworth, 2006; Wu, Krajcik, and Soloway (2001); Mayer, 1999; Treagust, Chittleborough, & Mamiala, 2003). Learning activities mediated by interactive simulations or computer-supported collaborative learning environments develop students' their scientific inquiry abilities while they construct scientific concepts (de Jong & van Joolingen, 1998; Laurillard, 2013; Perkins et al., 2006; van Joolingen, De Jong, & Dimitrakopoulou, 2007; Zacharia and Anderson, 2003). Teachers' selection and utilization of instructional resources (technology-relevant or not) should not be judged merely by local appropriateness within a particular topic, but also holistically, in accord with other instructional settings. Therefore, science teachers are now encouraged to become equipped with TPACK.

A teachers' knowledge is longitudinally developed and interwoven with their academic knowledge and the instructional disposition of the subject they teach. Previous research has been endeavored to epistemologically determine what constitutes teachers' knowledge (Angeli & Valanides, 2009; Mishra & Koehler, 2006; Shulman, 1986; Yurdakul et al., 2012). In fact, knowledge can be cognitively complex (Bloom, 1956; Krathwohl, 2002). TPACK as craft knowledge is knowledge-based and practice-required, and teachers are expected to engage a full range of cognitive processes when applying their instructional knowledge. It is common to see students' learning examined through tasks in which various levels of the cognitive process are engaged, but this is not yet the case for teachers learning TPACK.

2. Theoretical background

2.1. Nature and content of TPACK

TPACK can be fundamentally decomposed into the amalgam of pedagogical knowledge, content knowledge, and technological knowledge. Teachers' instructional knowledge can be complex and viewed as a three-tiered knowledge construct when disciplinary distinctions are considered (see Fig. 1). The first tier is *discipline specific* (or even *topic specific*) PCK (TPACK), which includes knowledge of pedagogical theories, subject matter, and instructional tools (or technological tools). At this stage, disciplinary distinctions like common misconceptions or specific instructional strategies are incorporated into teachers' PCK development (Magnusson, Krajcik, & Borko, 1999). The discipline specific PCK can be the goal of teachers' knowledge development, but at the same time it offers a foundation for further knowledge development. Moving to the second tier, teachers' PCK becomes *domain specific*. National Educational Boards also construct guidelines, standards, or benchmarks for teachers to follow, and these are often domain-specific. For example, the nature of science (NOS) and scientific inquiry are two objectives that science classrooms in the US emphasize (AAAS, 1993; NRC, 1996). Scientific literacy is another educational goal for science education to pursue (Norris & Phillips, 2003). The third tier of teachers' PCK development echoes the latest call in *trans-disciplinary* or *trans-domain* education (Kereluik, Mishra, & Koehler, 2010; Mishra, Koehler, & Henriksen, 2010). According to the *New K-12 Science Education Standards* (NRC, 2012), the US is pursuing the coherent incorporation of science and engineering education in technology-rich environments. It is common to see teacher education courses designed to develop teachers' PCK from discipline-specific to domain, while the development of teachers' *trans*-disciplinary PCK has begun only in recent years, and mainly in parts of the US and Europe (i.e., STEM).

TPACK is complex, not only as an integration of related professional knowledge but also when personal differences are considered. TPACK for science instruction can include pedagogical science knowledge (e.g., students' science misconceptions, effective instructional strategies like scientific inquiry, constructive approaches, science knowledge transformation through multiple representations, etc.), technological science knowledge (e.g., science-related technological resources like microcomputer-based laboratories, ICT-based problem solving approaches in science, etc.), and science-supported technological pedagogical knowledge (Jimoyiannis, 2010). The value of teachers' knowledge rests on their knowledge quality and "how it is put into action" (Abell, 2008, p. 140). Teachers' orientations, intertwined with personal experiences and beliefs, also critically determine their willingness and consistency when teaching with technology (Kagan, 1992; van Driel et al., 1998;

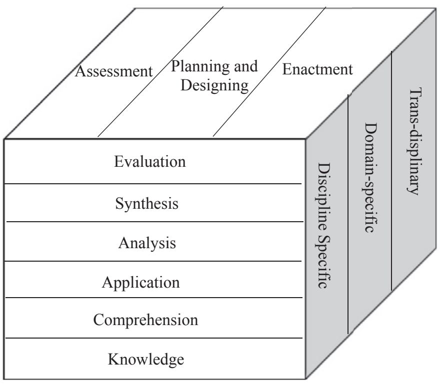


Fig. 1. Multiple aspects of TPACK.

Veal, 2004). Considering that there is no best or most appropriate way to teach (Mishra & Koehler, 2006), measurements for such a multi-faceted and dynamically changing knowledge construct should allow space for teachers to explicate their instructional reasoning.

2.2. Abstractness of TPACK

TPACK (or PCK) development should be a longitudinal learning objective for teachers, not only for personal knowledge development but also for instructional applications. To conceptualize teachers' learning of how to teach with technology, Bloom's taxonomy can be useful starting point. It deconstructs cognitive development in learning and focuses on the progression by which learners become masters of certain knowledge or skills (Bloom, 1956). However, such a simple-to-complex hierarchy was later modified and expanded because often, learning is not linear and may not independently occur throughout the various cognitive levels. For example, understanding might not be an absolute prerequisite for certain students' evaluation and creation (Anderson, 2005; Cox & Wildemann, 1970). Krathwohl (2002) adopted a constructivist perspective and revised the cognitive hierarchy into a cross-table of cognitive processes and knowledge dimensions. Both the original and revised taxonomies offer a reference to facilitate teachers' design and review of curricula and test items.

Teachers' acquisition of higher-order knowledge (e.g., *synthesis*, *evaluation*), which is analogous to student learning, requires different levels of cognitive processing to be engaged and hinged together. Therefore, in Bloom's taxonomy, *knowledge*, *comprehension*, and the *application* of instructional theories and strategies are fundamental steps, while *analysis*, *synthesis*, and the *evaluation* of instruction for different learning needs strengthen teachers' professional development. Researchers have found similar linear frameworks for teachers' TPACK development and mastery of certain technologies, processes that involve entry, adoption, adaption, appropriation, and invention (Niess et al., 2009; Niess, 2011; Rogers, 1995; Yeh, Lin, Hsu, Wu, & Hwang, 2015). Even in traditional classrooms, not all college teachers were found to be capable of guiding their students to practice higher-order thinking and demonstrate that thinking in front of their fellow students (Abrami, dÁpollonia, & Rosenfield, 2007). Considering that teaching is like problem solving, it is necessary to spend time investigating the breadth and depth of teachers' knowledge. Further insights into teacher education will be made once information related to teachers' cognitive sophistication and internal interactions is revealed.

2.3. Ways to evaluate teachers' TPACK

Teachers' performances offer valid and reliable matter for evaluation, especially when PCK is comprised of craft-based knowledge. Teachers' PCK can be captured by teachers' declarative knowledge (knowing that) and dynamic knowledge (knowing how) (Baumert, Blum, & Neubrand, 2004). Alonzo and Kim (2016) suggested measuring teachers' dynamic PCK, since this would reflect more of the flexibility of their knowledge when they are forced to make instructional decisions. Tasks like designing ICT-enhanced lessons and content-driven digital learning tools (Angeli & Valanides, 2009; Figg & Jaipal, 2009; Graham, Burgoyne, & Borup, 2010) are commonly used in teacher education, either for learning or evaluation purposes. Teachers' instructional reasoning can be witnessed in their group-work discussions and personal justifications associated with instructional artefact creation (Doering, Veletsianos, Scharber, & Miller, 2009; Koehler, Mishra, & Yahya, 2007). To further probe their design rationales, measurements like interviews and open-ended questions can be used to elicit teachers' knowledge, experiences, and beliefs about issues in situated contexts (So & Kim, 2009; Yeh, Lin et al., 2015).

According to the classic theory of situativity, learning is constructed through learners' participation and interaction within intact activity systems (e.g., Greeno, 1991; Lave & Wenger, 1991). Learning can rarely be transferred and is of little use if new situations are implemented and deep learning practices are absent (Boaler, 1997; Lave, 1988; Greeno & MMAP, 1998). Instructional clips offer rich situational information that teachers have acquired through their teaching experiences. Videotaping allows teachers to revisit, notice, and investigate their own teaching performances (Rosaen, Lundeberg, Cooper, Fritzen, & Terpstra, 2008). Teachers can also learn from reviewing, discussing, and criticizing peer teachers' instructional clips (Alonzo & Kim, 2016; Roth et al., 2011). Furthermore, videos of students' thought processes also offer excellent opportunities for discussion (Norton, McCloskey, & Hudson, 2011). However, these benefits are highly dependent upon the particular teacher's "ability to notice and interpret aspects of classroom practice" (van Es & Sherin, 2002, p. 8). Experienced teachers were found to be more capable of noticing details about and subtle differences in instructional strategies and students' reactions to lessons; inexperienced teachers tended to focus more on the teacher's role in instruction (Berliner, 2001; Carter, Cushing, Sabers, Stein, & Berliner, 1988; Sabers, Cushing, & Berliner, 1991). Presumably, teachers who are good at noticing students' learning needs and knowledgeable about alternative instructional strategies are also likely to be good at analyzing instructional performances.

2.4. Research problems

Evaluating teachers' TPACK (PCK) is not an easy task, not only due to the complex components mentioned above, but also because of the gaps between teachers' actual instructional knowledge and what can be observed. In this study, instructional clips were embedded in TPACK questionnaires in order to prompt teachers with instructional situations. Teachers' reflections and comments about the clips were elicited and scored according to whether the salient instructional aspects were recognized and considered via alternative or renewed perspectives. Different levels of the cognitive process were required to respond to these thought-provoking activities, including: describing, comparing, and criticizing instruction (Jay & Johnson, 2002).

This study attempted to address the following research purposes:

1 Construct questionnaires for use in evaluating science teachers' declarative and dynamic TPACK.
2 Identify key factors that contribute to science teachers' TPACK via responses collected from the discipline-focused and video-embedded questionnaires.
3 Explore the interrelationships among various factors, with the ultimate goal of unmasking how science teachers actually develop their TPACK from the perspective of cognitive process. Linear and cumulative loadings were hypothesized in the simple-to-complex cognitive process hierarchy.

3. Methods

High school science in Taiwan includes four subjects (i.e., biology, chemistry, earth science, and physics). Therefore, four sets of TPACK questionnaires were created; they shared generic item stems but differed from one another in their embedded discipline-focused clips. The rationales behind the item and video clip designs are presented in the sessions below. Churchill (1979) proposed a procedure for developing better measures for an intended construct. This study followed the sequence: target domain specification, item generation, purifying measures through pilot study, data collection, and reliability and validity checks. The processes for questionnaire and scoring rubric construction and validation are presented in Fig. 2. The final stage, regarding the psychometrics of the measurement process, is discussed in the results section.

3.1. Domain specification and item generation

Each item was designed to probe science teachers' TPACK with a focus on one single domain and one specific cognitive process. Features of the three knowledge domains and the five cognitive processes of which items were designed are detailed in Table 1. The three knowledge domains were the amalgam of the eight knowledge dimensions that expert teachers and researchers in Taiwan indicated as critical to science teachers' TPACK in teaching practices (Yeh, Hsu, Wu, Hwang, & Lin, 2014). These knowledge dimensions were later validated through 318 Turkish teachers' self-rating surveys (Ay, Karadağ, & Acat, 2015). Items included in the TPACK questionnaire used in this study were adapted from the indicators of the eight dimensions. Five types of item tasks were designed, based on the cognitive processes proposed in the original taxonomy (Bloom, 1956). Test items were either in dropdown format or open-ended questions. Items and item characteristics were presented in Appendix.

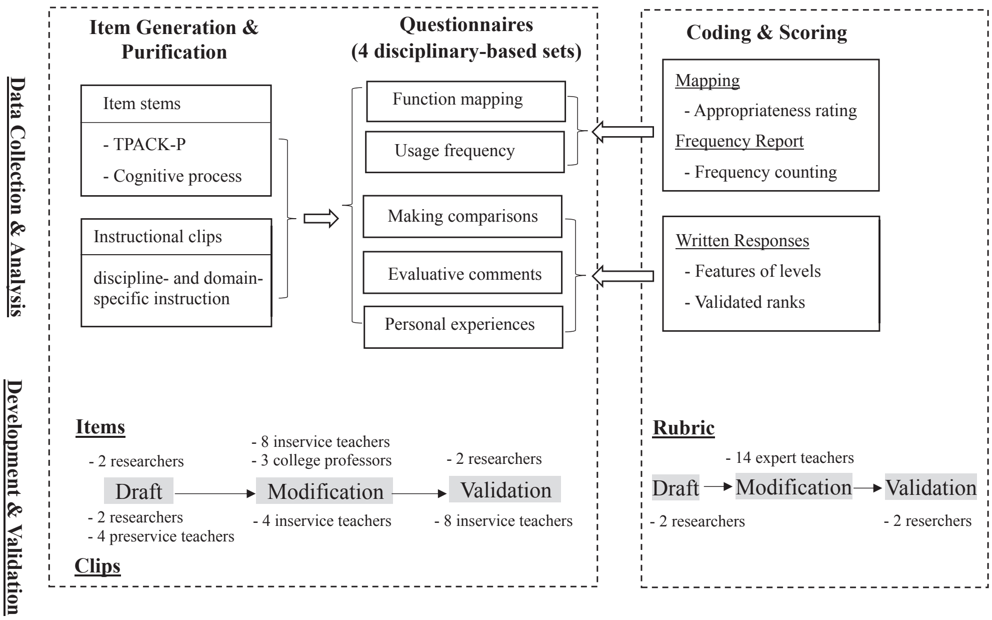


Fig. 2. Procedures in developing and validating questionnaires.

Table 1
Descriptions of target knowledge domains and cognitive process in TPACK questionnaires.

Dimensions	Descriptions
A - TPACK content about …	
Assessment	… ICT uses in student assessments (i.e., Using ICTs to know more of students, Using ICTs to assess students)
Planning and Designing	… planning and designing content-based courses with the assistance of ICTs (i.e., Using ICTs to understand subject content, Planning ICT-infused curricula, Using ICT representations to present instructional representations, Employing ICT-integrated teaching strategies)
Enactment	… implementing ICTs in teaching contexts or for instructional needs (i.e., Infusing ICTs into teaching contexts, Applying ICTs to instructional management)
B - Cognitive processes that teachers may engage when …	
Knowledge/Comprehension	… retrieving long-term TPACK (e.g., recalling) and constructing the pedagogical meanings of technological tools (e.g., classifying)
Application	… using technology in instruction for various purposes (e.g., implementing)
Analysis	… deconstructing or examining technology-supported instruction used for various purposes (e.g., differentiating, attributing)
Synthesis	… constructing courses with prior teaching experiences and (e.g., generating, formulating)
Evaluation	… judging the quality of technology integration in instruction (e.g., checking, critiquing)

3.1.1. *Knowledge/comprehension*

Item sets in the category of *knowledge/comprehension* asked teachers to identify possible affordances for the listed technological tools. For example, teachers were asked (via four items in a set) about their understanding of technology-based assessment. Each item focused on one specific technology: Item Response System (IRS), course management system (CMS, e.g., Moodle), an item bank CD-ROM, and concept mapping tool. As shown in Item Set - Example 1, teachers needed to rate how well these technologies afforded seven possible functions or usefulness that science teachers perceived in technology-based assessments (Chien, Wu, & Hsu, 2014). Other items enquired about teachers' knowledge of how instructional resource management technology could accommodate teachers' instructional needs. Related technology included: IRS, information searching (e.g., Google Search), instructional platforms (e.g., Moodle), online hard-drives (e.g., Drop Box), video editing software, and word processing software (e.g., Office).

Example 1. Q2. What functions do you think [IRS] can afford? Please rate their appropriateness. (1 for "least appropriate" and 5 for "most appropriate")

___ a. Offering immediate responses	___ e. Assembling tests
___ b. Providing records and log files	___ f. Sharing answers with others
___ c. Supporting multiple representations	___ g. Repetitively testing, free of time and space
___ d. Measuring students' understanding	

3.1.2. *Application*

Teachers' *applying* of TPACK was evaluated through their frequency in reporting different technological tools. For example, Example 2 asked the frequency of the teacher's use in technology-based assessment (i.e., IRS, CMS, concept mapping tools, game-based assessment, multimedia-supported questioning). Other items considered teachers' frequency of use of learning platforms (i.e., synchronous live forums, asynchronous communication platforms, IRS, CMS) and instructional resource management systems (i.e., instructional resource databases, video editing software, score management systems).

Example 2. Q1. How often do you use [IRS]?
___ Never heard of it
___ Only heard of it, or seldom use it (once or twice a semester)
___ Often use it (once a month or every week)
___ Frequently use it (almost every class meeting)

3.1.3. *Analysis*

Items concerned with *analysis* engaged teachers to attribute what made technology-supported instruction distinctive from conventional instruction, in terms of its different purposes. The strengths and weaknesses were coded as: 1) between technology-supported and paper-and-pencil assessments, and 2) between technology-supported instruction and conventional instruction.

3.1.4. *Synthesis*

TPACK at the level of *synthesis* can include teachers' knowledge that is formulated from their experiences and technology-supported instruction generation. After viewing and reflecting on the clips, the teachers were asked to describe how they themselves taught with technology. They were guided to report their selections and uses of technology in instruction, focusing on 1) adaptive instruction and 2) the target topics presented in the clips.

3.1.5. Evaluation

Teachers' TPACK at the *evaluating* level was probed through teachers' judgment-based comments regarding the instruction shown in clips. Each discipline-focused questionnaire was embedded with three thematic instructional clips, including 1) PowerPoint slides, 2) a 12–15 min microteaching video clip, and 3) a three minute screenshot clip of course preparation. Clips in one questionnaire shared same topic: photosynthesis (biology), atoms and molecules (chemistry), plate tectonic movement (earth science), and waves (physics). In the microteaching videos, the preservice teachers delivered their instruction with multimedia-supported PPT slides and a simulation-based learning tool designed to allow students to practice their new knowledge. The PPT slides in their microteaching videos in which the built-in animations and hypermedia links were active and available for viewers to click on and scrutinize (Fig. 3a). Predict-observe-explain (P-O-E) was the main instructional strategy preservice teachers used in their microteaching clips. (Fig. 3b). The screenshot clips recorded the preservice teachers' editing process as they prepared their instruction, such as when they trimmed off unrelated video parts and calculated scores using Microsoft Excel. Both the microteaching and course preparation clips were subtitled; the latter also used voice-over narration (Fig. 3c).

The teachers were required to respond to a total of five item sets, once they had viewed all the clips. The stem of these items were generic and without disciplinary content distinctions. Items asked teachers to judge the quality of the video teacher's performance with regards to their PowerPoint slide design, topic-based microteaching, and course preparation. Each item set required the teachers to indicate the strengths and weaknesses of the target teaching performance, and follow up with constructive comments. For example, after viewing the microteaching clips, teachers were asked to select two technological tools that the teacher in the clip had used and criticize how effectively he or she used them in the instruction (see Example 3). Other item sets required teachers to comment regarding their understanding of their students' learning progress, efficacy in completing instructional objectives, and utilization of instructional strategies. Finally, the screen shot clips prompted the teachers to comment on how the instructional resources and student learning records could be better managed.

Example 3. Q10. The teacher in the clip might use different ICTs to deliver the subject content. Please select two tools that he used and evaluate his implementation.
A. Images / B. Video Clips / C. Animations / D. Simulations / E. Micro-based Computers (MBL)

	Tool A:	Tool B:
- Strength		
- Weakness		
- Improvement Suggestions		

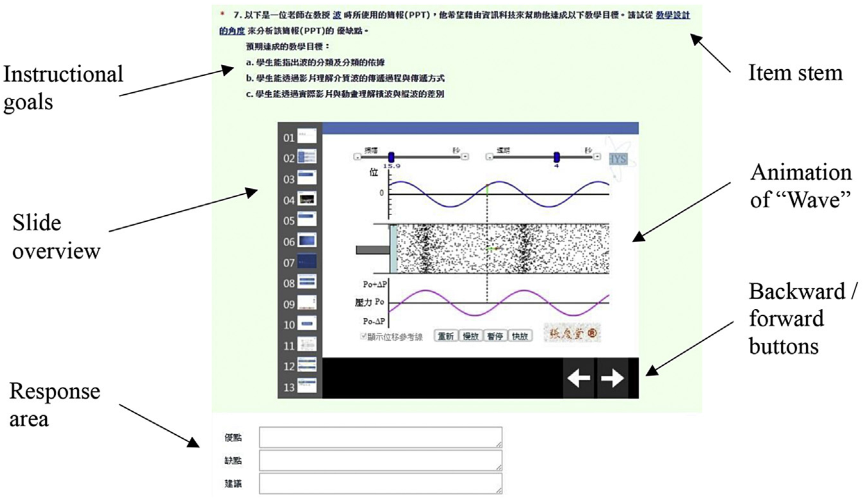
All of the questionnaire items and clip structures were drafted by a research panel (three professors, one research fellow, and one doctoral student) who had research interests in science education, e-learning, and teacher education (see Fig. 2). The PPT slides and instructional activities were created by the four preservice teachers, in order to ensure that the clips across the four disciplines shared the same structure (e.g., pedagogical strategies, multimedia types). Content validity was assessed through two rounds of questionnaire reviews. First, the draft of the three instructional clips in each discipline-focused questionnaire was reviewed and modified by one high-school teacher who was experienced in teaching that discipline with technology, ensuring that the clips captured real situations of instruction. Next, the four questionnaires, embedded with the clips, were posted online for another four experienced teachers from these disciplines to review and comment on the questionnaire quality. Finally, before the questionnaires were finalized, necessary modifications were also made.

3.2. Measure purification

The questionnaire drafts, which included item samples and video clips, were properly collaged and posted online according to the format used to present the official questionnaires. To complete the questionnaire trial, a pilot study recruited eight science teachers who taught with technology (two from each of the four disciplines) and three college professors whose research expertise was e-learning and science education; they were asked to pretend that they were the future respondents and offer comments regarding how the questionnaire could be improved. Necessary modifications were made by the research panel (the authors of this study) by reviewing and discussing the collected item responses and comments made regarding the questionnaires. Modifications included clarifying ambiguous word usage and ensuring that all functions of these online questionnaires worked as expected.

3.3. Data collection

A total of 99 science teachers filled out questionnaires, but responses from six were excluded because they were incomplete. All respondents were participants in professional workshops focusing on technology-enhanced instruction. The questionnaires were scheduled in 90 min sections, before lunch or the end time of the workshop. Participation was voluntary, but those who completed the questionnaires received a portable hard drive worth US $20 as an incentive.



a. PPT slides used in the physics microteaching clip

b. Microteaching clip for wave instruction

c. Screenshot clip of course preparation

Fig. 3. Clips embedded TPACK questionnaire for physics teachers.

Questionnaire participants usually took 60–90 min to watch the videos and respond to the item queries. Repeat viewings of the clips were allowed. The survey system set new items to appear once the previous items were completed.

3.4. Data analysis

Three types of data were collected; they were all scored differently (see Fig. 2). First, teachers' knowledge of how technological tools served different instructional purposes or facilitated content instruction was evaluated. Teachers needed to rate the appropriateness of each mapping of possible usefulness according to a 5-point Likert scale. The appropriateness of these mappings could be hard to judge, due to the many uses of technology in instruction and teachers' flexible knowledge. In fact, technological affordances still made certain instructional usefulness more or less accommodatable. Therefore, the appropriateness of each mapping was determined by the eight experienced teachers who were in charge of clip or item validation; this was followed up with researchers' ratings for triangulation. Since the appropriateness of teachers' uses could not be precisely defined, one point was offered if the teachers' ratings were within $\pm$ 1 of the ratings that experienced teachers gave, and zero points otherwise. Next, the frequency of the teachers' self-reporting regarding their use of technology was transformed into scores ranging from 0 to 2, with 2 points indicating a higher intensity. Finally, teachers' written judgment-based comments and related experiences were scored based on a rubric featuring different TPACK levels.

3.4.1. Rubric construction

The rubric was drafted based on the proficiency levels identified from science teachers' interview results (Yeh, Lin et al., 2015) and validated through standard-setting methods employed in item response theory (Jen, Yeh, Hsu, Wu, & Chen, 2016). Levels of teachers' TPACK included knowing but not implementing ICTs into instruction (Level 1 – Entry), implementing ICTs into instruction (Level 2 - simple adoption), meaningful and coherent collaborations with instructional elements (Level 3 - infusive application), and innovative or experience-based enactment (Level 4 - reflective application).

To construct a scoring rubric for the experience-based responses the TPACK questionnaires collected, it was necessary to gather advice from expert teachers. A total of 14 experienced science teachers from four disciplines were invited to a six hour workshop; the mission was to modify the preliminary rubric based on the scoring of responses from 54 cases. These expert teachers had 5–10 years of experience in teaching with technology and a total of 10–15 years in their respective teaching careers. Eight of these teachers had long-term collaborations with professors designing high school science curricula or science teacher education programs. In the first three hours, they trial-coded the responses within their respective disciplinary groups. During the second three hours, a cross-disciplinary discussion was conducted to modify the rubric and make it more descriptive of science teachers' TPACK, based on the trial-coding results. Finally, the four disciplinary panels did their formal coding, separately and with the modified rubric. These coding results were cross-referenced and finalized by two coders (the first and last authors of this research). Table 2 outlines the rubric for science teachers' TPACK in teaching practices (details of the rubric construction and its content were presented in a previous study, Yeh, Hsu et al. (2015)).

3.4.2. Scoring

Such a practitioner-modified rubric assumed that the higher the TPACK proficiency level of the science teacher, the more thoughtful, student-centered, and experience-based their rationale for using ICTs in science instruction. Criteria at the levels of Entry and Simple Adoption were involved more with teacher-centered strategies and ideas regarding conventional instruction, whereas criteria at the higher levels (i.e., Infusive Application, Reflective Applications) were involved more with the student-centeredness of teachers' thinking.

Teachers' TPACK at the level of application was estimated through the summation of technology usage frequency. Teachers' written responses were scored by how effectively or constructively they analyzed, synthesized, or evaluated technology-supported instruction, in terms of both student-centeredness and situative practicality. Examples of how we scored teachers' evaluations of the PowerPoint slides are shown below. Three responses in Example 4 were scored at levels 2 to 4. Case B4 judged the uses of multimedia and technological tools in the slides to be a strength (Level 2 – simple adoption); the threat that lacking content integration posed to students' knowledge construction was a weakness (Level 3 – infusive application). Case B9 offered suggestions for improvement from the perspectives of content presentation, instructional strategies, knowledge of and about science, and worksheet design (Level 4 – reflective application). Example 5 illustrates responses indicating that technological tools were being employed without describing their uses (Level 1 - Entry) and a wholly non-technological instruction or attempts (Level 0) for the item asking how the teacher used technology to support their students' adaptive learning.

The codes in the first bracket at the end of each response denote their level and the pattern being scored; references can be found in Table 2. A response may have multiple codes, but only the highest levels received were recorded.

Example 4.

Strength: 1. Uses of images and video clips made the content diversified. Simulation was also used when demonstrating the concepts. [E.SW2-2] [Case B4]

Table 2
Coding rubric for evaluating science teachers' TPACK.

	Analysis	Synthesis	Evaluation
0- Lack of Response	A0-1. Unable to point out any strengths/weaknesses.	S0-1. Explicates instruction which is not ICT-implemented.	E.SW0-1. Unable to offer ICT-related suggestions.
1 - Entry (Lack of ICT use)		**Possesses basic knowledge of ICTs in instruction.**	
	A1-1. Shows a basic understanding of ICTs in assessments/planning and design/enactment. A1-2. Describes ICT implementations with general comments (ex., good).	S1-1. Indicates universal principles of ICT usage, but without mentioning their particular uses.	E.SW1-1. Describes ICT implementation without specifying functions displayed in the videos. E.SW1-2. Indicates features of ICT-supported content presentation or instruction with general comments or general knowledge. E.C1-1. Indicates other ICTs or instructional methods without specifying how they are useful within the specific context. E.C1-2. Comments by indicating universal features of ICT-infused instruction that can be applied to different situations.
2 - Simple Adoption		**Considers ICT applications as they relate to the features of teaching, learning, and tools.**	
	A2-1. Identifies the functional strengths/weaknesses of ICT use in assessments/planning and design/enactment. A2-2. Attributes ICT-infused instruction from teacher's point of view or according to external concerns (e.g., a tight schedule, student motivations, teacher's technological literacy).	S2-1. Indicates that ICTs are used in his/her instruction, but lacks detailed descriptions of associated instructional practices or teaching rationales. S2-2. Implements ICTs in instruction for the purpose of presenting content or enhancing student learning motivations and/or comprehension. S2-3. Engages in teacher-centered/conventional teaching strategies when teaching with ICTs (e.g., uses multimedia that is premade, without editing or reproduction).	E.SW1-1. Judges the ICT implementation by indicating the function shown in the videos (e.g., concretizes the abstract concepts). E.SW2-2. Judges the ICT-supported content presentation by its explicitness to students (e.g., the possibility of generating alternative concepts). E.SW2-3. Judges the ICT-supported instruction by indicating features observed from the video instruction and the technology's general applications (e.g., use of discovery instruction increased student discussion time). E.C2-1. Offers comments by proposing other feasible ICTs or instructional methods as alternatives. E.C2-2. Proposes feasible solutions/appropriate modifications to the target teaching performance to facilitate teachers' instruction or students' comprehension. E.C2-3. Proposes suggestions to sort out external concerns or basic barriers for ICT-supported instruction.
3 - Infusive Application		**Considers ICT infusion from a practitioner's point of view.**	
	A3-1. Analyses the strengths/weaknesses of ICT use in assessment/planning & design/enactment by their instructional practicality. A3-2. Analyses ICT-infused instruction by considering students' learning progress or accommodations within the scope of the curricula or according to the instructional goals that they know of for this unit.	S3-1. Summarizes how he/she teaches with ICT-supported materials by explicating his/her instructional rationales and actions. S3-2. Implements diverse ICTs to deliver student-centered instruction or experiment construction (e.g., thinking experiments, logical inferences). S3-3. Prepares curricula based on students' learning progress or the diversity of the curricula (e.g., edits the premade multimedia or creates multimedia-based curricula).	E.SW3-1. Evaluates the ICT implementation from the perspective of student-centered learning (e.g., the simulation allowed students to manipulate different variables). E.SW3-2. Evaluates the ICT-supported content presentation based on students' science knowledge construction (e.g., students' misconceptions may still exit after instruction). E.SW3-3. Evaluates ICT-infused instruction by considering

(*continued on next page*)

Table 2 (*continued*)

	Analysis	Synthesis	Evaluation
			students' learning progress or learning effectiveness (e.g., group discussion allows students to share ideas and offers them opportunities to think). E.C3-1. Proposes feasible ICT implementations by explicating how they can be conducted in instruction. E.C3-2. Proposes student-centered instructional methods for difficult concepts or misconceptions. E.C3-3. Proposes modifications or elaborations to the ICT-infused instruction in videos within the scope of the curricula or according to the instructional goals they know of for this unit (e.g., related curricula, content comprehension).
4-Reflective Application	**Considers ICT-supported teaching practices with integrated views, reflective comments, or constructive feedback**		
	A4-1. Synthesizes the strengths/weaknesses of implementing ICTs into assessments/planning & design/enactment from a comprehensive point of view. A4-2. Synthesizes ICT-infused instruction by its educational logic and rationality based on the teachers' previous experiences.	S4-1. Indicates how ICT-infused instruction can be improved through reflective references to prior teaching experiences. S4-2. Arranges inquiry-based instruction to construct students' knowledge of and about science with appropriate uses of ICTs. S4-3. Rationalizes the design thinking of the multimedia-based curricula he/she develops; solves instructional difficulties or improves instructional quality innovatively, based on previous teaching experiences.	E.SW4-1. Evaluates ICT implementation, based on the teachers' previous experiences in facilitating students' learning. E.SW4-2. Evaluates ICT-supported content presentation from the perspective of the students' construction of their knowledge of and about science. E.SW4-3. Evaluates ICT-infused instruction by its educational logic and rationality, based on the teachers' previous experiences. E.C4-1. Proposes feasible programs based on previous experiences and learning from implementing ICT-supported instruction. E.C4-2. Proposes student-centered, inquiry-based instructional plans with flexible and appropriate uses of ICTs. E.C4-3. Customizes feasible ICT-infused programs after considering the scenarios given in the videos, based on their previous experiences.

Note: The first one or two letters in codes represent the cognitive process tasks. A and S stand for *analysis* and *synthesis*. E.SW stands for *evaluating* – strength and weakness, whereas E.C for *evaluating* – comment. The 1st number indicates the level and the 2nd for its serial number.

Weakness: PowerPoint slides included several different concepts without good integration; these were likely to make student learning difficult. Students were likely to get confused if the instructor did not explain clearly. The paths or the process of photosynthesis and cellular respiration were not clearly presented. [E.SW3-2] [Case B4]
Comments: 1. The slides explain the process and meaning of photosynthesis and cellular respiration. Uses of examples are helpful. 2. Materials like glucose, water, and CO2 are better presented in Chinese, with molecular formulas presented alongside. 3. The teacher should write keywords, procedures, and definitions on the board, and demonstrate related concepts through poster-posting. These strategies will help students follow up on the lecture during and after the slideshows. 4. The instructor should guide his/her students to discuss what factors impact plant growth at the end of the course, since they have been presented with the germination clips and simulations. 5. Worksheets and assignment should be designed to guide students to design experiments or discuss factors like temperature, water, and organism intensity in

Table 3
Loadings and variance of the rotated factors with the final retained item sets and their reliability.

	Factor 1	Factor 2	Factor 3	Factor 4
Factor 1 – Evaluation ($R^2 = 26.50\%$)	$\alpha = 0.80$			
E1. The teacher in the clips utilized technological tools to assist them to organize instructional resources (e.g., clip editing) and manage student learning records (e.g., score calculation in Excel). Please evaluate his technology use on these two aspects.	0.94			
E2. The teacher in the clip use different ICTs to deliver the subject content. Please select two tools that he used and evaluate his implementation.	0.74			
E3. The teacher in the clip used different instructional strategies to assist their student learning. Please select two instructional strategies that he applied and evaluate his practices.	0.55			
Factor 2 – Synthesis/Evaluation ($R^2 = 13.70\%$)		$\alpha = 0.76$		
S/E1. How did you teach [wave] or related topics? Please specify your technology and instructional strategy uses.		0.82		
S/E2. Please evaluate how the teacher in the clip used technology to better know more of his students and develop an improvement solution for the teacher to implement student-centered instruction.		0.67		
S/E3. How can these technological tools facilitate teachers' instruction of [wave]?		0.62		
Factor 3 – Application/Analysis ($R^2 = 9.85\%$)			$\alpha = 0.77$	
A/A1. How do you think technology-based assessments differ from paper-and-pencil assessments?			0.69	
A/A2. How often do you use the technology-based assessments - IRS?			0.68	
A/A3. How often do you use [synchronous live forum] in your instruction?			0.65	
A/A4. What did you consider when you planned your technology-supported instruction? Please explain how these factors influenced your planning.			0.61	
Factor 4 – Knowledge/Comprehension ($R^2 = 9.62\%$)				$\alpha = 0.72$
K/C1. What functions do you think [IRS] can afford? Please rate their appropriateness. (See Item Example 1)				0.85
K/C2. Please rate how useful [IRS] can be in supporting the four instructional behaviors as listed below. (1 for “least appropriate” and 5 for “most appropriate”)				0.83

*Loadings were based on pattern matrix.

groups. 6. Students' learning motivation will be enhanced through their self-manipulation of the simulation, if time and the facilities allow. [E.C4-1, E.C4-2, E.C4-3] (Case B9)

Example 5.

Personal instruction: *Simulation.* [S1-1]
Personal instruction: *Collect students' opinions through semi-structured questioning.* [S0-1] (Case P9)

3.4.3. Inter-rater reliability

The inter-rater agreement between the two coders was 82% after the first round of independent coding; the rate improved to 100% after another two rounds of separate coding and discussions.

4. Results

Exploratory factor analyses (EFA) was conducted in order to determine the factorial structure of science teachers' TPACK. Considering that errors of statistical inference can be sensitive to sample size, we followed the rule established in Gorsuch (1983) regarding using a subject-to-item ratio of 5:1 when doing factor analyses. Each questionnaire was composed of 17 item sets; there were between 1 and 7 items in each set. We summed the teachers’ scores for each item set, viewing them as an estimation of the target knowledge domain. An EFA was conducted to explore the major factors from the 17 total scores that the 93 teachers received. For the underlying factors, the internal consistency of the items was reported.

4.1. Factor analysis

An EFA with a Promax rotation was conducted to explore critical factors and select discriminating items from the TPACK questionnaires. Results from the Kaiser Meyer Olkin measure of sampling (KMO = 0.76) and Barlett's test of sphericity ($X^2 = 328.40$, $df = 136$, $p < 0.00$) indicated that the data collected from the science teachers were appropriate for the EFA (Kaiser & Rice, 1974; Sharma, 1996). The eigenvalues of the major factors were set to be larger than one, and one item with a loading of less than 0.30 was eliminated. Another Promax-rotated EFA was conducted after the less-loaded item sets were eliminated in order to determine the factor structure. In the final results, the 12 item sets of teachers' scores were grouped

Table 4
Correlation matrix among the four levels of cognitive process.

	[min. − max.]	M (SD)	Knowledge/Comprehension	Application/Analysis	Synthesis/Evaluation
Knowledge/Comprehension	0–63	24.05 (5.67)			
Application/Analysis	0–45	16.97 (4.59)	0.23*		
Synthesis/Evaluation	0–37	23.86 (4.84)	0.23*	0.25*	
Evaluation	0–54	19.26 (5.58)	0.31**	0.24*	0.39*

Note. $N = 93$; $^{*}p < 0.05$, $^{**}p < 0.01$.

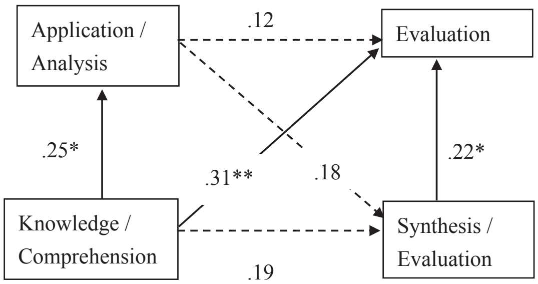


Fig. 4. Path coefficients of science teachers' cognitive process in TPACK development (Standardized coefficients).

into four oblique factors (as shown in Table 3). Excellent items had loadings >0.71, while very good items had loadings >0.63, and good items had loadings >0.55 (Comrey & Lee, 1992). As shown in Table 3, the loadings of the 11 items ranged from 0.55 to 0.94, implying that the 30%–88% variances were explained by their underlying factors. The total variance explained by these four constructs was 58.59%. The number of items ranged from 16 to 63 within a single factor, and the reliability of the items within the same factor was between 0.72 and 0.80.

Through EFA, the extracted factors were *evaluation*, *evaluation/synthesis*, *application/analysis*, and *knowledge/comprehension*. *Evaluation* was found to best explain variances in their TPACK development ($R^2 = 26.05\%$). Items that were grouped into Factor 1 were originally designed to elicit teachers' TPACK through tasks involving evaluating others' instructional performances on technology uses. Factor 2, *synthesis/evaluation*, subsumed two item sets enquiring about teachers' knowledge formulated from experiences of offering topic-based instruction and one set that engaged teachers in an evaluation task with a focus on knowing students with technology uses (S/E2). Items in Factor 3 evaluated teachers based on their technology use frequency in instructional contexts (*application*) and performances in differentiating technology–supported assessments to traditional tests and organizing critical factors to their personal technology-supported instruction (*analysis*). Finally, Factor 4, *knowledge/comprehension*, included items for measuring teachers' knowledge of how the listed technological tools could be functionally supportive of teachers' instructional behaviours, such as properly editing materials, maintaining students' learning records, and conducting assessments.

All the item sets for the science teachers to respond were designed with one single TPACK domain and one specific cognitive process. The extracted factors were mainly organized from the perspective of cognitive processing, instead of knowledge domains. Such results implied that teachers' TPACK performance were influenced by task complexity, which was attended with levels of cognitive demands as well. A clear boundary was found absent between *synthesis* and *evaluation* (Factor 3) and *application* and *analysis* (Factor 2). It can be due to the fact that the two processes within each pair were adjacent to each other in Bloom's hierarchy.

Table 5
Direct, indirect, and total effects of the four cognitive process development.

	Predictors	Direct effect			Indirect effect		Total effect	
		Coefficients	*se*	R^2	Coefficients	*se*	Coefficients	*se*
Application/Analysis				0.06				
	← Knowledge/Comprehension	0.25*	0.10				0.25*	0.10
Synthesis/Evaluation				0.08				
	← Knowledge/Comprehension	0.19	0.12		0.04	0.04	0.23*	0.12
	← Application/Analysis	0.18	0.13				0.18	0.13
Evaluation				0.22				
	← Knowledge/Comprehension	0.31**	0.11		0.08*	0.05	0.39***	0.11
	← Application/Analysis	0.12	0.12		0.04	0.03	0.16	0.12
	← Synthesis/Evaluation	0.22*	0.10				0.22*	0.10

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

4.2. Path analysis of the cognitive process

Four factors relating to the levels of cognitive process were identified from the EFA results. These levels are engaged with different degrees of cognitive complexity: higher-level cognitive processes (i.e., *synthesis*, *evaluation*) presumably pre-require or build upon the lower-level cognition processes (i.e.,*knowledge/comprehension*, *application*). A path analysis was conducted to investigate the linear relationships among these four cognitive processes in terms of teachers' TPACK development. As the linear hierarchy foretold, knowledge/comprehension was set as an exogenous variable and the other three process (i.e., *application/analysis*, *synthesis/evaluation*, *evaluation*) were endogenous variables. Significant correlations were found among science teachers' TPACK performances at these four cognitive levels (see Table 4).

As shown in Fig. 4, the estimated paths between *knowledge/comprehension*, *application/analysis* ($\gamma = 0.25$, $p < 0.05$), and *evaluation* ($\gamma = 0.31$, $p < 0.01$) were significant. These science teachers' *knowledge/comprehension* did not show significant contributions to their *synthesis/evaluation* directly ($\gamma = 0.19$, $p > 0.05$), but the total effects became significant after indirect effects were considered ($\gamma = 0.23$, $p > 0.05$) (see Table 5). In contrast to the importance of *knowledge/comprehension* to the development of the three other higher levels, teachers' *application/analysis* made insignificant contributions to teachers' TPACK at the *synthesis/evaluation* ($\beta = 0.18$) and *evaluation* ($\beta = 0.16$) levels. Considering the small correlations with the three other cognitive processes (see Table 4), we can attribute the insignificant paths partially to standard errors. Teachers' TPACK at the *synthesis/evaluation* level was found to be predictive of their TPACK at the levels of *evaluation* ($R^2 = 0.22$, $p < 0.05$) level. Overall, science teachers' TPACK at higher-order levels explained more variances in their TPACK development, though teachers' understanding and application of technology in their instruction are fundamental constructs, as suggested in Bloom's taxonomy.

5. Discussion

Inservice teachers' TPACK can be very different from that which preservice teachers develop, because teaching experiences and beliefs can personally vary and situatively interact. Teachers' knowledge should first be developed *for* practice and then *in* practice, and ultimately become *of* the teacher's (Cochran, DeRuiter, & King, 1993; Cochran-Smith & Lytle, 1999, p. 250). We have conducted a series of studies, beginning with identifying the components of inservice teachers' TPACK (Yeh et al., 2014), then moving to unmasking the distinctive features of TPACK at different proficiency levels (Yeh, Lin et al., 2015), and finally to standardizing the scales of these proficiency levels and their distinctive features (Jen et al., 2016). Based on these studies, we constructed video-embedded questionnaires that were featured with clips of technology-supported disciplinary instruction and items that engaged teachers to operate their TPACK at via different cognitive processes. The EFA analysis extracted four factors that were cognitively involved in science teachers' TPACK development (i.e., *knowledge/comprehension*, *application/analysis*, *synthesis/evaluation*, and *evaluation*). The path analysis results indicated that teachers' technology implementation frequency may not be predictive of teachers' attainment of higher-order TPACK, though it is practice-based knowledge.

Measurement designs are one major merit of this study. Video-simulated tasks allow teachers to demonstrate their in-the-moment instructional reasoning (Alonzo & Kim, 2016; Santagata & Bray, 2015) and the clips offer rich resources for teachers to reflect upon or respond with (Rosenstein, 2008; Santagata & Guarino, 2011; Santagata, 2009). Clips of actual science classroom can be better resources than the microteaching ones in terms of the contextual authenticity, but it may not be true for the sake of assessment standardization and assessment difficulty. For example, science is a subject that demands students construct their own knowledge of and about science Driver, Asoko, Leach, Scott, & Mortimer, 1994). The value of PCK should be teachers' flexibility in negotiating concerns like students' misconceptions or phenomenon investigations, as well as that adopting appropriate strategies to teach certain topics (Alonzo & Kim, 2016; van Driel, Berry, A. & Meirink, 2014). Micro-teaching clips can be pre-planned with a science-specific repertoire of instructional strategies (e.g., P-O-E, inquiry) and instructional-based technology uses (e.g., simulation, animation), in addition to other strength of presenting situational clues within limited time span. Most of all, the assessment content (e.g., instructional clips, test items) need to be standardized, especially when each questionnaire was designed and intended for science teachers from different science disciplines. Clips may be free of the requirement of standardization if they are used for purposes like within-group discussions. In addition, clips of paradigmatic teachers may display the smooth integration of technology into instruction, but their instruction can be difficult to criticize, especially for teachers who are novices in teaching with technology. Preservice teachers' instruction can be imperfect, but this leaves space for viewers to reflect and critique.

Knowledge that learners seek to acquire and master should include both concrete content and abstract knowledge (Carson, 2004). However, in reality, teachers' learning of TPACK seems limited to topics related to their particular interests (such as effective content instruction), rather than assessments, classroom management (Fives & Buehl, 2008; Kaya, 2009; Padilla & Van Driel, 2011). Design-based activities are also common learning tasks for teachers, such as distance course design, simulation-based APP and learning module design (Yeh, Hwang, Hsu, & Wu et al., 2015; Mishra & Koehler, 2005). Now that there are several studies investigating the key domains of TPACK at the content level (Angeli & Valanides, 2009; Kabakci Yurdakul et al., 2012; Mishra & Koehler, 2006), the cognitive processes extracted from teachers' responses should be no less important, and the elaboration of teachers' TPACK should be avidly pursued. This study found teachers' performances on tasks that demand similar cognitive operations were extracted to be a part of the same group or in groups near one another (i.e., *application/analysis*, *synthesis/evaluation*). Fuzzy boundaries have been a problem since the 1970's when researchers attempted to locate the cognitive processes students engaged with in their learning (Anderson, 2005; Cox & Wildemann, 1970). If we accept the fact that boundaries are unclear in nature, the activities for teachers will still be meaningful and constructive only if all four indispensable cognitive operations are engaged.

When exploring how these cognitive processes interacted in the teachers' TPACK, *evaluation* was found to best explain variances in their TPACK development. Such results correspond with previous findings regarding the importance of teachers being continuously self-reflective and judgmental about their instructional performances (Hatton & Smith, 1995; Kagan, 1992; van Es & Sherin, 2002). A good evaluating ability has been found to be one of the critical indicators of teachers having good PCK (Borko, Jacobs, Eiteljorg, & Pittman, 2008). It is surprising that the higher-order cognitive processes were not loaded by the lower ones, especially when the higher processes are assumed to be built upon the lower. Higher-order theories may explain such reversals, arguing that higher-order processes determine what enters the first stages of conscious awareness (Lau & Rosenthal, 2011). The importance of *application/analysis* may correspondingly diminish, especially with higher-order cognitive processes are engaged. We may also attribute the grouping of use frequency (*application*) and claim knowledge (*analysis*) to their distance from other instruction-oriented factors (*synthesis*, *evaluation*). Teachers with frequent and diverse technology uses in their technology-supported instruction were not necessarily the same as those with more highly developed *knowledge/comprehension*, *synthesis* and *evaluating*. For example, some teachers may view themselves experts in technology-assisted instruction, even though they were frequent users of slides displays without the engagement of good and flexible instructional design. Under the assumption that technology-related practices are believed to be recursively funded back to teachers' TPACK, the breakdown by *application/analysis* within this hierarchy suggests the need to fill the void in teacher empowerment (e.g., in-depth discussion or actual incorporation of technology in instruction).

The format of e-questionnaires allows more accessibility to teachers and researchers, but there are limitations to the current study. First, the development of *trans*-disciplinary TPACK (the third tier) was not considered in the measurement design, given that no official STEM programs were pursued in Taiwan until now. STEM projects were launched in the US around 2000 to address the declining number of students enrolled in STEM classes, as well as a generally lower level of student interest and poorly prepared teacher workforce (National Math + Science Initiative, 2014; National Science and Technology Council, 2013). Measuring teachers' *trans*-disciplinary TPACK will be indispensable for future teacher education and professional development. A second limitation is that while online questionnaires can be useful for collecting large-scale samples, the open-response format requires time for completion and scoring. Keeping the subject-to-item ratio at 5:1 is a well-established and practical rule, but some studies have expanded this ratio to as much as 20:1. A larger sample size will better control for the likelihood of errors, which would mean a better factor extraction solution (Costello & Osborne, 2005). Third, the study sample was composed of participants in workshops related to teaching with technology. Therefore, the results of this research will be useful to teachers and teacher educators interested in how to teach science with technology.

6. Conclusion

Teachers' knowledge is a complex construct that transforms individually and is defined situatively. Analogous to student learning, measurements for teachers' knowledge development are useful if the distinctiveness of the teacher can be accommodated and instructional dispositions elicited from authentic situations. Evaluations do not need to be for assessment purpose only; instead, learning and evaluation can be mutually enriching. Instructional clips can offer useful resources for teachers to study, reflect upon, discuss, and even be assessed by, if the clip selection and evaluation rubrics are properly attended. In addition to the progressive stages that other researchers have identified in teachers' TPACK development, it should be noted that teachers' TPACK that operates higher-order cognitive processes is not necessarily constructed at the lower process levels, such as application and analysis. Rigorous effort needs to be made in strengthening teachers' *knowledge/comprehension*, since it plays pivotal roles in determining the quality of the input (content, technology, pedagogy, or its integration). Mere uses of technology with a lack of pedagogical reasoning may not be critical to teachers' attainment of higher-order TPACK processing. Advances in technology have led to a call for teachers capable of developing meaningful uses for technology, but knowledge sophistication needs to be secured before quality instruction can be sustained.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.compedu.2016.10.006.

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