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Experiences and reflection have long been regarded as a foundation for pedagogical content knowledge (PCK) development. However, little is known about how experienced teachers develop their PCK via reflection-in-action during their moment-to-moment classroom instruction. Drawing upon data sources including classroom observations, semi-structured interviews and stimulated recall interviews based on lesson videos, this study examined instances when four experienced teachers were found to *invent* new instructional strategies/representations *on the spot* during the lesson (referred to as on-site PCK development) in their first attempts at teaching a new topic. The study documented the moment-to-moment experiences of the teachers, including their reconstructed thought processes associated with these instances of on-site PCK development. An explanatory model of a three-step process comprising a stimulus, an integration process and a response was advanced to account for the on-site PCK development observed among the teachers. Three categories of stimulus that triggered on-site PCK development were identified. Factors influencing the integration process and, hence, the resulting response, included teachers' subject matter knowledge of the new topic, their general pedagogical knowledge and their knowledge of student learning difficulties/prior knowledge related to the new topic. Implications for teacher professional development in terms of how to enhance teachers' on-site PCK development are discussed.

Keywords: *Pedagogical content knowledge (PCK); Teaching new topics; Polymerase chain reaction (PCR); Reflection-in-action*

Introduction

Classroom environment has been characterized as complex, simultaneous and unpredictable (Doyle, 1986). Science classrooms are no exception and can present unique and unusual situations where teaching and learning do not always unfold in anticipated ways. For example, science teachers often have to talk their way out of it

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when a science experiment or a demonstration does not work out as planned (Nott & Smith, 1995). Nor is it easy to make appropriate responses to unanticipated students' ideas about scientific phenomena (Coffey, Hammer, Levin, & Grant, 2011). The problems are exacerbated if teachers need to cover the curriculum within a limited instruction time, not to mention the challenges of catering for students with learning diversities. In summary, teachers need to develop a rich, flexible and integrated knowledge base to make sense of immediate scenes so as to make on-the-spot decisions in the face of unanticipated circumstances. While teachers draw upon their knowledge to inform their *in situ* decision-making, teacher knowledge also develops within the crucible of the classroom. Although it has been known for decades that a reciprocal relationship exists between teacher knowledge and classroom actions, this complex relationship is not yet well understood (de Jong & Van Der Valk, 2007).

Pedagogical content knowledge (PCK) is one construct for describing teacher knowledge. Since its inception, PCK has been regarded as the professional knowledge base of science teachers that distinguishes them from scientists (Cochran, DeRuiter, & King, 1993; Veal & MaKinster, 1999). PCK has also been identified as essential to quality science teaching in educational reform documents (National Research Council, 1996) and in science teacher preparation (Anderson & Mitchener, 1994). Consequently, there have been calls for developing professional science teachers through enhancing their PCK development (Kind, 2009). Within the PCK literature, much has been written about how PCK may support teachers' instruction (Alonzo, Kobarg, & Seidel, 2012; Jones & Cowie, 2011), yet little is known about how teachers may construct their PCK from their moment-to-moment teaching experiences. The present study attempts to fill this gap by exploring the phenomenon of how experienced science teachers *invent* new instructional strategies/representations on the fly during their lessons. It presents cases of how PCK may or may not be developed from the moment-to-moment teaching acts of the teachers.

Literature Review

In the following sections, we first discuss the literature on teacher knowledge to provide a framework for situating the present study. We then discuss the relevant literature that shaped our study.

Pedagogical Content Knowledge

PCK was identified as a unique province of knowledge in teachers by Shulman (1986, 1987). He conceptualized PCK as 'the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction' (Shulman, 1987, p. 8). As such, transformation of content knowledge into viable instructions lies at the heart of PCK (Abell, 2007; van Driel, Verloop, & de Vos, 1998; Park & Oliver, 2008b). Some scholars view PCK as existing at a more generic level, such as discipline-/domain-specific PCK (Davis & Krajcik, 2005; Veal & Kubasko, 2003). However, it is more widely accepted that PCK concerns the teaching of a *particular* topic (i.e. PCK is topic-specific) (van Driel et al., 1998; Hashweh, 2005). As a result, teachers need to develop topic-specific PCK for *all* the science topics that they teach (Magnusson, Krajcik, & Borko, 1999). Such topic-specific PCK development is particularly crucial when a teacher teaches a topic for the first time.

PCK is a complex construct (Loughran, Mulhall, & Berry, 2004) consisting of integrated and intertwined knowledge components (Abell, 2008). Two knowledge components appear to be central (van Driel et al., 1998): (1) knowledge of instructional strategies and representations (KISR) and (2) knowledge of students (KS). The former category refers to teachers' knowledge and understanding of representations (e.g. examples, models, illustrations and analogies) and activities (e.g. problems, demonstrations, simulations and experiments) for teaching a particular topic. The latter includes teachers' knowledge and understanding of the prerequisite knowledge for learning the content in question and the variations in students' approaches in learning as well as what students know about the topic (e.g. students' difficulties in learning and misconceptions). In the context of teaching a new topic for the first time, it is highly likely that teachers need to develop *new* KISR to make otherwise difficult science concepts accessible to students.

Different Ways of Conceptualizing PCK Development

By and large, PCK development can be conceptualized in three ways in the research literature. Some view PCK development as an *integrative* process. For example, Marks (1990) regards development of PCK as revolving around teachers' interpretation of the content and the specialization of their general pedagogical knowledge (PK) in relation to that content. According to this view, PCK development entails an improved integration of teachers' knowledge. Other researchers view PCK development as an *inventive process*. Hashweh (2005), for example, suggests that PCK represents recollection of 'cases of repeated experiences of teaching a familiar topic' (p. 289) by teachers, and new PCK develops when they construct a new analogy for explaining a difficult concept. From this perspective, PCK development pertains to the expansion and elaboration of an existing knowledge base or, put simply, repertoire enrichment. Still others regard PCK development as a knowledge *refinement* process. For example, Lee, Brown, Luft, and Roehrig (2007) used a three-level rubric to assess the quality of PCK developed by their beginning teachers over time. They rated the student teachers' PCK as limited, basic or proficient based on the scientific accuracy and pedagogical effectiveness of the instructional strategies/representations therein. In this approach, PCK development refers to a better quality of knowledge.

No matter how PCK development is conceptualized, it is believed that teachers are not 'born' with PCK (Kind, 2009). Instead, teachers develop PCK in the context of planning, teaching, reflecting on and re-teaching a particular topic (Hashweh, 2005; Magnusson et al., 1999). In the context of the present study, we viewed PCK development as an *inventive* process.[1] We focused on instances of teachers' invention of new KISR occurring in the interactive phase of the lesson (see rationales below), and we called this 'on-site PCK development'.

Unpacking On-Site PCK Development

Experience of teaching a particular topic is necessary, but insufficient, for a teacher to develop PCK. Experience must be coupled with thoughtful reflection for PCK development. PCK may develop when teachers reflect in real time *during* the act of teaching (i.e. reflection-in-action) and *after* instruction (i.e. reflection-on-action) (Schön, 1983, 1987). Although the role of reflection in PCK development has been clearly established in the literature, a survey of the literature (see Table 1) suggests that PCK researchers have largely focused on how PCK develops when teachers reflect *on* their classroom experiences (Friedrichsen et al., 2009; Park

Table 1. Relevant literature on teachers' development of topic-specific PCK

	Lens for examining PCK development	KS	KISRs
Reflection *in* action	Knowledge invention/ refinement	• Teachers develop understanding of students' learning difficulties and misunderstanding based on questions posed by students in class (van Driel et al., 2002)	• There is a lack of in-depth investigation on on-site PCK development
	Knowledge integration	• Critical moments occurring in the classroom demand teachers to draw on their PCK at their disposals to deal with the incidents. This leads to a better integration of PCK components (Park & Oliver, 2008b)	
Reflection *on* action	Knowledge invention/ refinement	• Teachers develop new understanding about students' learning difficulties when reflecting on their practical experiences of teaching the topic (de Jong & van Driel, 2004; de Jong, van Driel, & Verloop, 2005)	• Teachers develop intentions to invent new instructional strategies/representations (de Jong et al., 2005; Park & Oliver, 2008b) or better understand the limitations of the instructional strategies/ representations (de Jong et al., 2005) through reflection on their practical experiences of teaching the topic
	Knowledge integration	• Teachers integrate their knowledge (i.e. SMK and PK) and transform the knowledge to form PCK when they reflect on critical moments occurring in the classroom (Nilsson, 2008). Structured reflection on teachers' own teaching experiences pushes teachers to integrate different PCK components (Park & Oliver, 2008a)	

& Oliver, 2008a). There is little research unpacking teachers' PCK development associated with their 'reflection-in-action'. Ironically, this is despite empirical evidence suggesting that this could be a fertile ground for research. For example, van Driel, de Jong, and Verloop (2002) found that teachers may acquire a better understanding of students' difficulties (i.e. KS) through listening to students' questions posed during instructions. More recently, Park and Oliver (2008b) found that teachers develop topic-specific PCK that is more *integrated* as a result of their responses to unexpected moments in their teaching. However, few studies, if any, have explored in depth how teachers *invent* new instructional strategies/representations *on the spot* during their lessons (i.e. development of KISR) (i.e. on-site PCK development).

Several independent lines of research have also suggested that experienced teachers' instructions are adaptive, emergent and flexible, pointing to the possibility of on-site PCK development. These lines of research include research on teachers' interactive cognitions (Borko, Livingston, & Shavelson, 1990), expert mathematics teachers' PCK (Borko & Livingston, 1989), science teachers' adaptive teaching (Allen, Matthews, & Parsons, 2013), science teachers' use of analogies (Dagher, 1995; Thiele & Treagust, 1994) and teachers' instruction in science practical work (Nott & Smith, 1995). However, these prior studies seldom indicated clearly whether the instructional strategies/representations the teachers drew on during the lessons were created *in situ* (i.e. invention of something novel that the teachers had never done before), or whether the teachers were just recalling and repeating something that they had done before even though it was not included in the lesson plan. In cases where *in situ* creation of knowledge was implied, these prior studies fell short of examining in depth the teachers' thought processes associated with such on-site invention of new instructional strategies/representations.

In light of this, this paper reports on an initial attempt to explore teachers' thought processes associated with on-site PCK development. The inquiry was part of a broader study in which we aimed to understand how experienced teachers coped with teaching a new science topic in light of a curriculum change in Hong Kong. As the inquiry continued and the data emerged, we noticed various instances in which the teacher participants *invented* new instructional strategies/representations *on the spot* during the lessons. We took the opportunity to probe deeper into the teachers' thought processes associated with successful instances as well as unsuccessful instances (see Methods) of on-site PCK development. Such an in-depth analysis would deepen our understanding of how and why PCK may or may not develop from teachers' moment-to-moment classroom experiences. As such, findings of the study may shed light on possible ways to foster on-site PCK development.

Research Questions

We posed the following research questions in this part of the research:

(1) What are the possible stimuli that trigger on-site PCK development?

(2) What are the inhibitory and facilitative factors influencing on-site PCK development?

Methods

Research Design

The larger study investigated the PCK development of four experienced science teachers with varying years of teaching experience (6–22 years) (Table 2) in their *first-time* teaching of a *new* topic in light of a curriculum change. The broader study adopted a qualitative case study approach (Merriam, 1998; Stake, 1995) and was naturalistic and exploratory in nature. The case study approach was chosen because the phenomena under study (teacher knowledge, teacher decisions, teaching practices and their inter-relationships) were complex and inextricably linked with the context (the teacher, the students and the classroom context). These dynamic phenomena could not be fully scrutinized without a thick and in-depth description of the study context. The study adopted an interpretive paradigm (Erickson, 1985). The aim of the study was to determine from the perspectives of the actors (the teachers) why they acted in a particular way when teaching the new topic.

There are two noteworthy points regarding our research design. First, we situated our study in the teachers' first-time teaching of the new topic such that their prior PCK for teaching the new topic was minimal (Loughran, Berry, & Mulhall, 2006). Under such circumstances, it would be more likely for teachers to *invent* new instructional strategies/representations. Second, we chose experienced teachers *within* a subject specialization as our participants. We believe that, compared with their counterparts outside the subject specialization, the experienced teachers should have a wealth of knowledge (including their disciplinary content knowledge) and prior teaching experiences to draw upon as a resource to develop new topic-specific PCK to teach the new topic.

Research Context

The study was situated in Hong Kong at the time of a curriculum reform. A new topic from frontier science—Polymerase chain reaction (PCR)—had been incorporated into the Biotechnology elective of the New Senior Secondary (NSS) biology curriculum.

Table 2. Information of the participating teachers

Name	Gender	Education	Science background	Teaching years
Alex	Male	B.Sc./M.Phil./M.Sc.	Biochemistry	14
Brandon	Male	B.Sc./M.Ed.	Biology	23
Chris	Male	B.Sc./M.Phil.	Biochemistry	6
Dennis	Male	B.Sc./M.Sc.	Biology	8

The study was conducted when the experienced biology teachers taught the new topic to their NSS Secondary 6 (S6) (aged 17–18 years) students for the *first* time.

Data Collection

In the larger study, data were collected from an array of sources, including classroom observations, field notes, classroom artefacts and in-depth semi-structured interviews to capture how teachers' PCK develops in their first attempts to teach the new topic. The primary data source for this part of the research was the Post-lesson Interviews held immediately after the lessons, which captured the teachers' reconstructed thought processes associated with the observed on-site development of PCK. Teachers were first prompted to recount any unexpected moments/incidents and/or changes in the lesson agenda that had occurred during the lessons. Based on the recalled events, teachers were stimulated to reconstruct their thought processes associated with those moments, including the stimulus that had triggered them to invent a new instructional strategy/representation on the spot and the various knowledge bases that they had drawn on. Following a similar procedure, the second phase of the interview shifted the focus to teaching episodes where the teachers were employing instructional strategies/representations that they did not mention in their lesson plans and Pre-lesson Interviews (see Appendix A for the semi-structured interview protocols). A total of 17 Post-lesson Interviews were conducted, each lasting from 20 to 60 minutes.

Before proceeding, two limitations of the methodology used in the present study to probe into teachers' thought processes associated with on-site PCK development should be noted. First, the study relied on the teachers' retrospective reports of their own observations in class and the reconstruction of their own thought process associated with their on-site PCK development. There is no guarantee that these self-reports of thought processes and reflective experiences represented those during the lessons. Another caveat is that these retrospective accounts may involve *post hoc* rationalization of their observed student behaviours and/or stimuli that had triggered their on-site PCK development.

Data Analysis

Data analysis occurred in two phases. In the first phase, the interview transcripts were first analyzed using codes corresponding to the PCK components of an established framework (Magnusson et al., 1999) (Appendix B). In brief, the codes are teachers' (1) KISR, (2) KS, (3) knowledge of curriculum and (4) knowledge of assessment (see Appendix B for details). In the coding process, the presence of the PCK components and the corresponding evidence were identified by analyzing the associated interview transcripts that revealed the teacher's knowledge. In cases where clarification for coding was needed, we referred to other data sources (e.g. classroom artefacts and lesson video transcripts) for further evidence and for triangulation of our data (see Appendix B for more details). The coded transcripts were examined for evidence of teachers' KISR developed *on the spot* during the lesson. For each instance of on-site PCK development, the corresponding transcripts of the lesson video, the associated interview and the classroom artefacts were pooled together for further analysis. The ultimate goal was to present the research findings in form of a classroom vignette (see Findings). Each classroom vignette comprised a detailed description of the classroom interaction, the instructional strategies/representations used and the teachers' thought processes, including their pedagogical reasoning/reflection. The description of the classroom interaction was mainly based on the lesson video and classroom observation supplemented with other data sources (e.g. classroom artefacts). The teachers' thought processes were reconstructed by the researchers through reviewing and analyzing the relevant interview transcripts with due emphasis on the following two aspects: (1) the stimulus that provoked on-site PCK development and (2) the factors contributing to that development. Each vignette is accompanied by a PCK reporting table (Appendix C) (Park & Oliver, 2008b) and a figure summarizing the major events leading to on-site PCK development and the factors affecting it (see Findings).

In the second stage of analysis, the whole data-sets of the larger study (involving more than 70 interviews and 30 lesson observations) were reviewed to identify unsuccessful instances of on-site PCK development. Unsuccessful instances refer to those classroom situations that could have, *from the researchers' perspective*, resulted in on-site PCK development on the part of the teacher concerned, but had not in reality. The purpose of identifying these missed opportunities to develop new KISR was to explore the factors inhibiting the development of new KISR. These unsuccessful instances were identified using the following criteria. First, the instance was reported by the teachers, in the Post-lesson Interviews, as an unexpected moment occurring in their classroom (i.e. teachers experiencing a difficulty or troubling event). Second, a potential stimulus for on-site PCK development (as identified in the first phase of data analysis reported above) was identified in the lesson video, as well as in the teacher's reconstructed thought processes in the Post-lesson Interviews. In other words, classroom situations satisfying the above two criteria actually represent instances which were *noticed* by the teachers as an opportunity to act, and yet they failed to do so.

The teachers were then shown videos of these lesson episodes in Stimulated Recall Interviews to trigger their reflection *on* those moments. For instance, they were asked whether they were satisfied with their teaching in the episodes captured in the videos as well as about their possible modifications in their next round of teaching (Appendix A). Teachers' reflection on the videos showing moments of their missed opportunities to act provided another data source for identification of factors inhibiting on-site PCK development.

The major findings were verified in the member check interviews. The interview quotes and the final portrayals were also mailed electronically to the teachers for them to review the data as well as to suggest corrections, rejections and elaborations on the interpretations. All teachers agreed with the interpretations and the findings.

Findings

A summary of the main findings, including the total number of instances of on-site PCK development, is reported first. This is followed by classroom vignettes illustrative of successful and unsuccessful instances of on-site PCK development, coupled with the teachers' reconstructed thought processes in those moments.

Summary of the Main Findings on On-Site PCK Development

Table 3 presents a synthesis of the data. All teachers were assigned pseudonyms to ensure confidentiality. Altogether, 9 instances of on-site development PCK within the 30 lessons videotaped were identified.

As Table 3 presents, more than one piece of KISR may be developed in a single instance of on-site PCK development. No particular pattern can be discerned in terms of the type of instructional strategies/representations developed by the teachers.

Illustrative Vignettes for Instances of On-Site PCK Development

The three possible types of stimulus that triggered on-site PCK development included: (1) unexpected student responses; (2) environmental stimuli and (3) unanticipated student questions. Three vignettes of on-site PCK development are presented below, one for each category of stimulus. The vignettes document the teachers' reconstructed thought processes in the Post-lesson Interviews, providing a window into their reflection-in-action associated with on-site PCK development. Each vignette starts with the conceptual context concerning PCR to aid readers' understanding of the vignettes.

Vignette 1: the replication of bacteria and the replication of DNA in PCR. PCR is a molecular technique which allows the selective amplification of a small quantity of DNA to large quantities. Such amplification is crucial for subsequent analysis of DNA samples in many different applications such as DNA fingerprinting.

Table 3. Occurrence of on-site PCK development in this study

Participant	No. of lessons videotaped	Type of instructional strategies and representations: Illustrations	Examples	Analogies	Others	Total no. of instances of on-site PCK development	Total no. of pieces of KISR developed
Alex	10	1	1	0	2	3	4
Brandon	11	0	1	1	0	2	2
Chris	7	0	2	0	1	2	3
Dennis	2	1	1	1	0	2	3

The teacher, Dennis, planned to revisit students' ideas on DNA fingerprinting by asking his students to identify the problem in working with only a very small amount of DNA (e.g. one single strand of DNA molecule). In planning the lesson, Dennis thought that it should be easy for his students to understand that working with one molecule of DNA would make the subsequent staining and visualization of DNA in DNA fingerprinting difficult. From that, he could then explain the role of PCR in DNA fingerprinting (i.e. amplifying a very small amount of specific DNA fragments to a larger amount). However, after posing the question, Dennis found that the students still did not understand why working with a single molecule of DNA was problematic (see the transcript in Appendix C for details of the vignette). He then made an on-site move as follows:

D: Imagine a situation. There is a cell. There is only one cell, can you see it?
D: Previously, I taught you how to grow bacteria, right?

Dennis was drawing the image of a culture plate on the blackboard.

D: Now, we have inoculated some bacteria.
D: [The bacteria] can't be seen [now]. When will you be able to see the bacteria?
S2: When they grow in number to form bacterial colonies

Dennis was adding some bacterial colonies on the diagram he drew.

D: Yes. When they turn into bacterial colonies!
…
D: Now, the same situation we have is like that.
D: It is really so unlucky that you have just isolated one single molecule of DNA.
D: When you have performed analysis in DNA fingerprinting, are you able to see [the DNA]?
Ss: [The DNA] can't be seen.
D: After you have done the (DNA fingerprinting) analysis, the DNA can't be seen, right?
Students nodded their heads. Dennis then went on to introduce the function of PCR in amplifying the DNA for DNA fingerprinting. (Lesson Transcript #1)

Dennis explained why he had drawn the diagram (transcript lines 4 and 10) on the blackboard in the Post-lesson Interview:

> I immediately came up with it. … My memory on teaching them the topic Transgenic Organisms just flashed in my mind, I talked about bacterial colonies. … Initially, I expected that this would be a relative easy question for the students. But then, they really couldn't come up with the answer to my question (i.e. If you really perform DNA fingerprinting analysis, in your view, how would this (i.e. small amount of DNA) affect you (your analysis)?). … I then used that analogy. … I was thinking about the replication of cells … The concept of replication is also applicable to bacteria. It is the same as the replication of DNA in PCR. (Post-lesson Interview #1)

In this case, the stimulus that triggered on-site PCK development was unexpected student response (i.e. students' failure to give appropriate answers). The transformation of the scientific concept was facilitated, in part, by Dennis's understanding of his students' prior knowledge (i.e. the concept that only after bacteria had divided often enough to form bacterial colonies would they become visible) as a result of his recent experience teaching the topic Transgenic Organism and his personal understanding of the function of PCR. He was able to 'transfer' the concept of replication of DNA to the replication of bacteria. Indeed, this instance of on-site PCK development was also informed by his preference for using analogies as an instructional strategy to help students' grasp abstract science concepts. As he put it:

> I think that after saying the analogies, it would be easier for them to understand. Some concepts are very abstract. … I really like using analogies. I like to think about analogies. Usually, they are created inside the classroom. I would look around and think; then I would come up with new analogies. (Post-lesson Interview #1)

In summary, the *stimulus* that had triggered the PCK development was the students' failure to respond to the teacher's question. The *integration* process involved retrieving the relevant KS (i.e. the students' prior learning experience of Transgenic Organisms) to explain the concept the students were struggling with. The *response* was the creation of a new analogy (i.e. the replication of bacteria (individually, cannot be seen by the naked eye to form bacteria colonies (which can then be seen by the naked eye)). The events are illustrated in Figure 1.

Vignette 2: the function of primers. PCR consists of three repeated steps, one of which is the annealing of primers. Primers are short chains of polynucleotides which bind to specific regions of the DNA strands. One of the functions of primers is to provide a starting site for DNA polymerase to continue the extension of the growing DNA strand. In planning the lesson, Alex did not prepare, in advance, any instructional strategy to explain this particular function of primers. Nevertheless, he decided to talk more about the concept during the lesson. He explained in the Post-lesson Interview:

> Actually, if you can help students link their knowledge in other subjects to the new knowledge, it would be easier for them to learn. Normally, new learning builds on prior knowledge. … If you can probe their old knowledge to build the new knowledge, then it would be the safest approach. … I didn't plan to talk about the meaning of primers. I just suddenly thought that it was needed. (Post-lesson Interview #1)

The transcript below shows the part of the lesson that Alex referred to.

A: Before I talk about the process of annealing, I need to talk about primers first. Where have you heard of this word?

Students were shaking their heads to show that they had not heard of the word before.

A: What is the meaning of '–mer'? Monomer, polymer? What is '–mer'?
A: '–mer' refers to unit.
A: Primer, what is it? Primer. Primer, what does it mean? Where have you seen the word 'prime'?
Ss: Primary Schools
Ss: Prime Minister

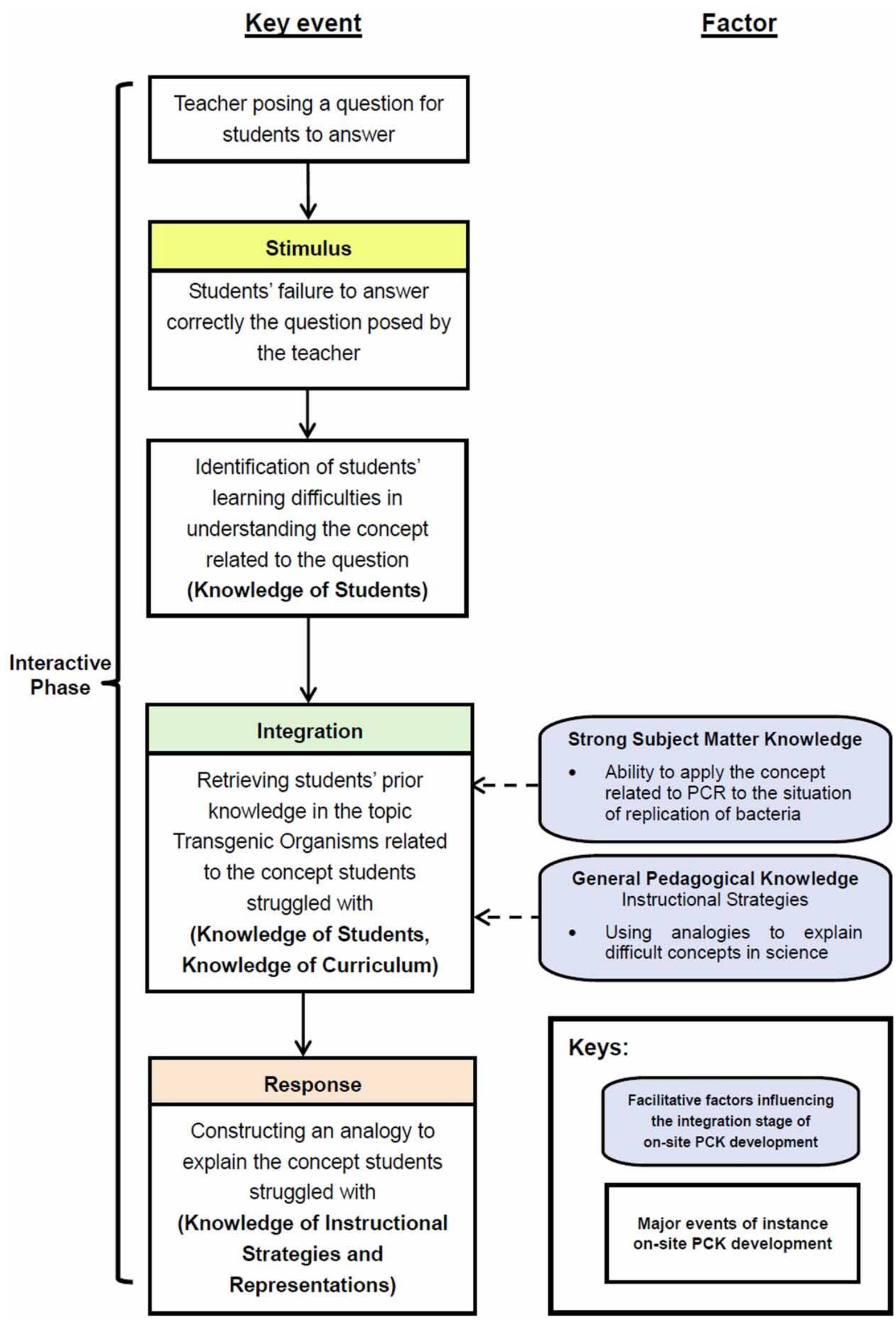

Figure 1. Dennis's instance of on-site PCK development in Vignette 1

A: Prime Minister, primary school … So what does it mean for primer?
Ss: Elementary level
A: Elementary level or primitive.
A: '-mer' refers to a thing. Primer, so what does it mean? What is the meaning of primer?
A: The Chinese meaning is '引物.' (The literal meaning for the first Chinese character '引' is attracting, directing or guiding; and the second character '物' means an object. The two words combined together mean 'an object which is responsible for a guiding function.)
A: Let's guess what is the meaning of 引物? What to 引 (i.e. to attract)? What to prime? Priming what? 引 what? What is the word to follow? What is related to it? It can prime what?

The students looked confused. Alex sensed that students did not know what Chinese word he was referring to. Then he wrote on the blackboard the word '引'

Ss: 引言 (Introduction) … 引導 (Directing)
A: Yes, 引導 (Directing). That's right!
A: 引導 (Directing). Then, what is the meaning of primers and what does it mean? What does it direct?
Ss: Nucleotides.
A: Directing the nucleotides? What is the name of this reaction?
Ss: Polymerase
A: Polymerase? Polymerase chain reaction. So, what to prime?
Ss: Polymerase.
A: It primes the polymerase to where it should begin working. (Lesson Transcript #1)

It looks as if the newly invented instructional strategy (i.e. talking about the meaning of the split words, 'primers' and '-mer') to explain the function of a primer (i.e. providing a starting site for polymerase to begin to work) (transcript lines 6–9) was triggered by Alex's noticing of students' facial expressions of confusion (transcript lines 25–26). Actually, noticing students' confusion was just another stimulus reinforcing Alex's *initial* on-site decision to carry on with the newly invented instructional strategy; as he put it:

> I didn't plan to talk about the meaning of the word primer. Suddenly, it occurred to me that this was needed. When I was talking about polymerase, I saw the word '-mer.' I immediately knew that I needed to 'handle' the meaning of the word 'primer' itself as the suffix '-mer' is also present in the word primer. (Post-lesson Interview #1)

He further elaborated:

> If students do not know the meaning of '-mer' (the Chinese equivalent is '物'), they won't be able to know the meaning of primer in Chinese—'引物.' This, in turn, may affect their understanding of why a primer is needed in PCR. (Post-lesson Interview #1)

In other words, the *initial* stimulus for the on-site development of this instructional strategy was an environmental one (i.e. seeing the word 'polymerase'). This helped Alex to retrieve his KS (see below regarding their prior knowledge of the suffix '-mer'). Importantly, it was Alex's strong PK (i.e. his understanding that new learning builds on prior knowledge) that prompted him, on seeing the word 'polymerase' (stimulus), to see the opportunity to use the word 'primer' to further develop his lesson —something that he had missed in his planning.

Alex's decision to invent a new instructional strategy was reinforced as he noticed students' confusion with the meaning of the Chinese word 引. He further explained why he had used the Chinese translation of 'primer' (i.e. '引物') to aid his explanation (transcript lines 17–23):

> For the word 'primer', students may not know the meaning of 'prime'. They should know the meaning of '-mer' because they have learned—polymer, monomer. But for the prefix 'prime', they may not be able to relate it to something that they are very familiar immediately. Actually the exact meaning is well encapsulated in the Chinese translation of the term '引物.' I think the Chinese translation is good. The word '引' (literally means 'directing') can help students to think of the function of primer, which is to direct the polymerase where to start working. (Post-lesson Interview #1)

The above suggests that this on-site PCK integration process was facilitated, in part, by Alex's strong PK—his general understanding of students (i.e. students' potential difficulty in understanding the meaning of the English word 'prime') and his KS' prior knowledge (i.e. students have learnt the words 'polymer' and 'monomer' elsewhere). From what he says below, it appears that Alex was able to draw on this instructional strategy (i.e. asking students to derive meanings from spilt words) instantaneously because of his frequent use of the relevant strategy in his teaching.

> For example, when teaching 'chloroplast', I would ask students 'what is meant by -plast? What is the meaning of chloro-? Is there any relationship between chloro- and chlorine?' I always teach students in this way. … If you have more experience, you will be more sensitive to this method … It is because you use [this strategy] normally. (Post-lesson Interview #1)

To summarize, the initial *stimulus* for the on-site development in this case was environmental—seeing the word 'polymerase' on the blackboard. This, in turn, made Alex re-seize a previously overlooked opportunity to help students tackle a potential learning difficulty through building on their prior knowledge. The initial stimulus was augmented by noticing students' confusion about the meaning the Chinese word '引' during the lesson. The *integration* process involved retrieving the relevant piece(s) from his KS' prior knowledge (i.e. they had learned words like polymer and monomer elsewhere before and they should know the Chinese translation of primers) to explain the meaning of word 'primer'. This resulted in the *response*—the teacher's creation of new instructional strategies in class (i.e. asking students the meaning of the split words and of the ideographs). The key events are depicted in Figure 2.

Vignette 3: the role of DNA loading dye in PCR product analysis. After PCR amplification, the DNA samples (i.e. PCR products) are usually analyzed using agarose gel electrophoresis. Since the resulting DNA samples are colourless, a coloured DNA loading dye is needed in the process to track the progress of the movement of colourless DNA samples in an electric field (i.e. during gel electrophoresis)[2].

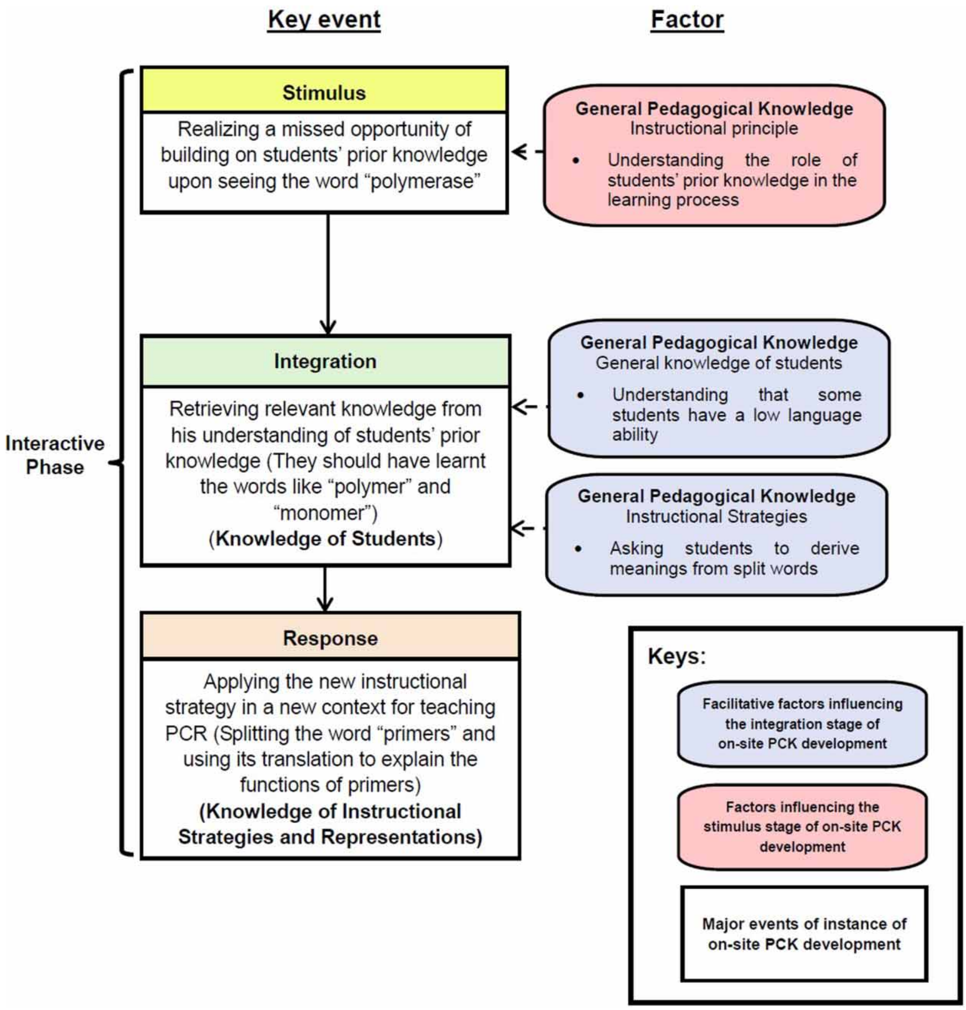

Figure 2. Alex's instance of on-site PCK development in Vignette

The third teacher, Chris, explained the concepts surrounding DNA loading dye in a didactic manner. In the Post-lesson Interview, Chris spoke of noticing a misconception he had inferred from an unanticipated question raised by a student during the lesson:

> Students were not clear about why the loading dye moves [during the electrophoresis of PCR products] … . A student asked a very high-order question. She asked, 'as the dye should have no charge, why can it move?' At the moment, I thought she might be wondering whether it is because when the DNA moves, it would pull the dye to move alongside; or it is the dye moving on its own because of some unknown reasons. (Post-lesson Interview #2)

Chris was able to identify the misconception revealed by the student's question immediately (i.e. that dye used in the analysis of PCR products should have no charge) because of his strong subject matter knowledge (SMK). He addressed it by spontaneously generating a counter example (i.e. coloured chemical ions can have charges) to clarify the matter (transcript lines 10–11):

C:	Can you see the dyes (in different lanes of the gel)? Are they moving at different speeds?
C:	For the distance they moved, are they different?
	Chris was pointing at a photograph of an agarose gel with loading dyes.
C:	The dyes in different lanes move to this position.
C:	Actually, it is to tell you that the dye intrinsically has charge.
C:	Even if it has charge, it can still be a dye.
C:	Actually all of you have studied, in chemistry, many ions have colours. Our dyes can have charges. A dye can have charges.
C:	Of course, we need to select some negative charged dyes. You won't select some positive charged dyes for loading into the gel.
C:	If you load positive dyes into it, what would be the consequence?
Ss:	Sticking together
C:	Sticking together? They won't stick together.
C:	Because when you perform electrolysis, normally, you find a beaker of water, a beaker of salt water, when you put the electrodes in what would happen?
Ss:	Inaudible
C:	What separates?
Ss:	Inaudible
C:	The ions. The positive ions would move to the negative pole. The negative ions would move to the positive pole.
C:	If you use normal salt water, you would be able to see that on one side, hydrogen would evolve, and on another side oxygen would evolve. You have learnt that in, chemistry right?
Ss:	*Nodding*. (Lesson Transcript #2)

Chris used the example of the electrolysis of water (transcript lines 17–18) to explain that charged ions would separate in the electric field instead of 'sticking together' (transcript line 15) as his students believed. He explained to the researcher how he had come up with the examples he generated on the spot:

> Initially, students thought that dyes should have no charges. … I wanted to show them some examples that actually some coloured materials can have charges. I chose to make use of the example of ions because I knew that they had learnt this [concept] in chemistry. … It was difficult for them to memorize what the colours of the ions are. I have not thought about this when I planned for the lesson. I don't know. … I wanted to prove to the students that ions can be coloured too [and so do the dyes]. Suddenly, this example flashed [in my mind]. (Post-lesson Interview #2)

In this instance, Chris' on-site PCK development was clearly supported by his KS' prior learning experience (i.e. students had already learnt about electrolysis) as well as his general knowledge about students (i.e. students have a hard time memorizing the colour of chemical ions in their chemistry lessons). He was therefore able to think on his feet and create a counter example (i.e. chemical ions). This counter example was considered familiar and meaningful to his students as his students had a hard time memorizing the colours of the ions.

To sum up, on-site PCK development can be regarded as a three-step process (i.e. stimulus, integration and response) (Figure 3). The *stimulus*, in this case, was the teacher's realization of a student's misconception in a student's question, the

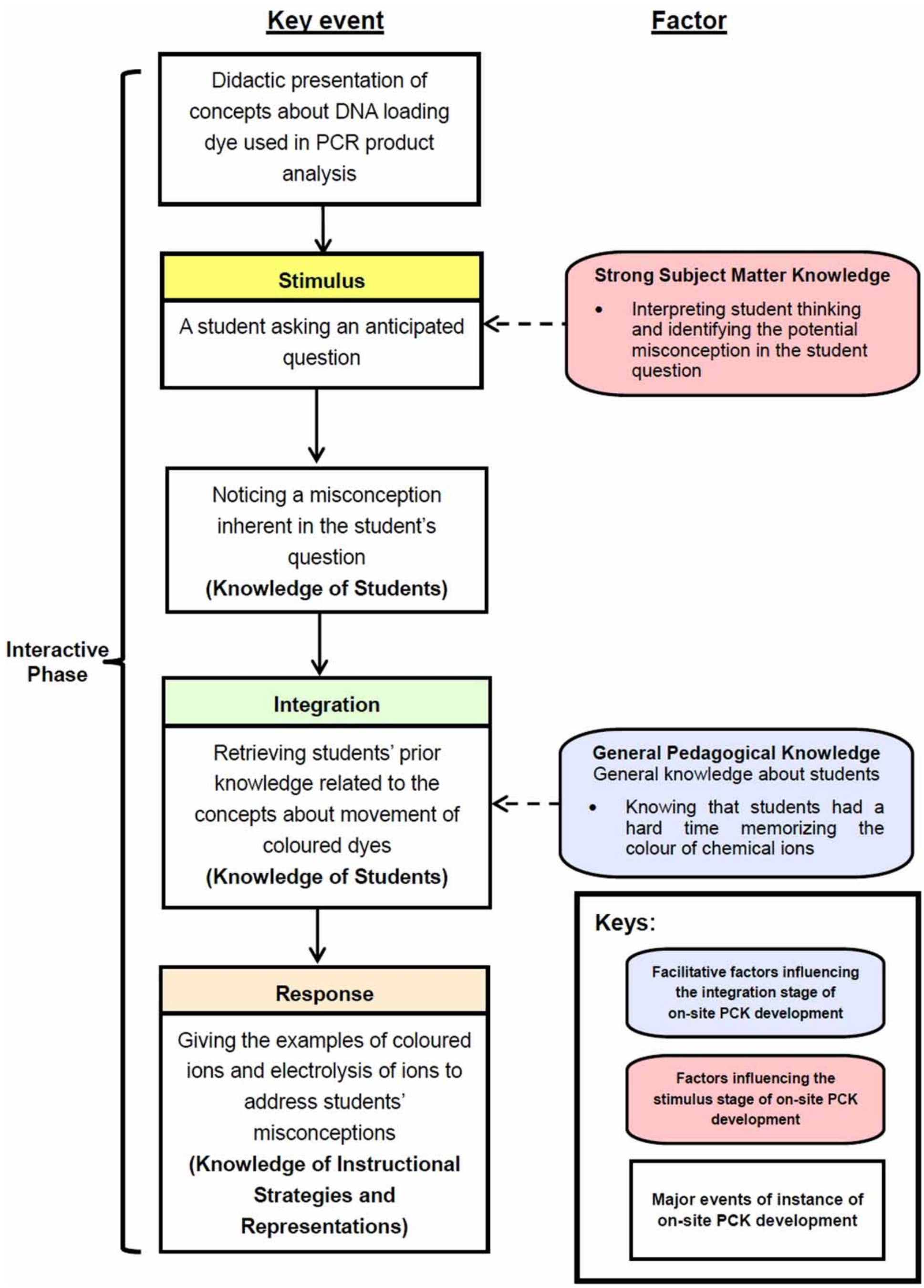

Figure 3. Chris's instance of on-site PCK development in Vignette 3

integration step involved retrieving relevant KS (i.e. the student's prior knowledge of chemistry) and the *response* was to give the student the examples to clarify the misconception.

To summarize this section, the facilitative factors for on-site PCK development that can be identified from the three instances include: (1) teachers' strong SMK; (2) teachers' strong PK, including their preferred instructional strategies and general understanding of students and (3) teachers' KS, including their prior learning experience and their potential learning difficulties related to the topic, PCR.

Illustrative Vignettes for Non-Instances of On-Site PCK Development

Three unsuccessful instances of on-site PCK development were identified in the data corpus. Two illustrative instances were selected. The following portrays the moment-to-moment experiences of the teachers as well as the teachers' pedagogical reflections *on* these episodes as elicited in the Post-lesson/Stimulated Recall Interviews.

Vignette 4: The function of primers. Dennis thought students could readily answer his question, 'How can we make sure that the DNA synthesis starts at the desired part [of the DNA]?' He raised this question to the class by pointing at the DNA diagram on the PowerPoint slide. After examining six proposed answers from his students, Dennis gave the 'correct answer' due to the students' failure to answer the posed question. He directly told the class that the result could be achieved by putting 'an object, called the primer, in the desired position to restrict the polymerase to copy this [DNA] segment'. When asked what he felt about the lessons he had just conducted during the Post-lesson Interview, Dennis promptly recounted details of the event and reflected on it:

> The concepts of primers are difficult to the students. They spent quite a lot of time thinking about [the question] on primers. … I expected that they could come up with the correct answer quickly. Nevertheless, when I look back, if they can't come up with [that idea], it is quite difficult to guide them towards that idea. (Post-lesson Interview #1)

Dennis was clearly alluding to his lack of a repertoire of instructional strategies to help students understand the function of primers. His failure to create a viable strategy to explain the function of primers on the spot could be understood as a result of his inadequate understanding of the subject matter:

> I am not 100% sure whether the primers and the DNA polymerase have any special interaction. What I mean is whether something has been added to the primers such that the [DNA] polymerase would be able to recognize it. … I was thinking whether there is such interaction … But, there doesn't seem to be any. So, I didn't talk about this interaction. (Post-lesson Interview #1)

From his accounts, it seems that Dennis himself was struggling with the concepts related to primers at the critical moment. This, in part, explains why he did not have the intellectual capacity to construct a new instructional strategy. It is also obvious, from the above statements, that Dennis had an insufficient understanding of the concepts related to primers. He did not realize that, for the DNA polymerase to function, it had to attach to one end of the primer (i.e. interaction exists between the polymerase and the primers). His failure to grasp this concept may also account for his inability to create new instructional strategies/representations on the fly. Hence, one possible inhibiting factor in on-site PCK development could be inadequate SMK. The major events related to this instance are illustrated in Figure 4.

Vignette 5: the function of thermostable enzymes. Chris recounted in the Post-lesson Interview an unexpected moment that arose from his reaction to an unanticipated student question:

> Actually, a student, Kathy, asked a question: 'Why can't human DNA polymerase be used in PCR in place of a thermostable enzyme?' Actually, I didn't expect students to ask that question. (Post-lesson Interview #1)

Indeed, the requirement of a thermostable enzyme in PCR is a critical concept often unexplained in textbooks (Martínez-Gracia, Gil-Quýlez, & Osada, 2003). Although Chris was able to offer an answer on the spot in a didactic manner, he reflected on what he had done and suggested how he should have dealt with the critical incident better after he had been shown the video episode in the Stimulated Recall Interview:

> Next time, if no one asks this question, I would ask students this question and have them discuss on it. … This time, because of a lack of experience, when the question was asked, I naturally answered her. … I should have given students more time to think and discuss. I think I should have capitalized on this question for them to think. (Stimulated Recall Interview)

Chris appeared dissatisfied with his spur-of-the-moment response. As can be inferred from his own reflections on this instance, the on-site transformation of SMK into appropriate instructional strategies was somewhat inhibited by his lack of experience in teaching the topic (i.e. his knowledge of these particular students' learning difficulties). He therefore answered the question didactically instead of formulating new ways to explain the relevant concepts or representing the concepts in other ways. The major events associated with this instance are illustrated in Figure 5.

To summarize this section, evidence amassed from these two non-instances suggests that inhibiting factors for on-site PCK development include: (1) teachers' inadequate SMK and (2) teachers' insufficient KS (i.e. understanding of specific students' learning difficulties).

Discussion

In his early work, Hashweh (2005) speculated that PCK can develop in the interactive phase of teaching. What has thus far appeared in the literature is limited to a broad brush painting of the challenging nature of on-site PCK development (McDuffie, 2004; Sanders, Borko, & Lockard, 1993). For instance, Sanders et al. (1993) simply reported that the experienced science teachers in their study 'felt constrained'

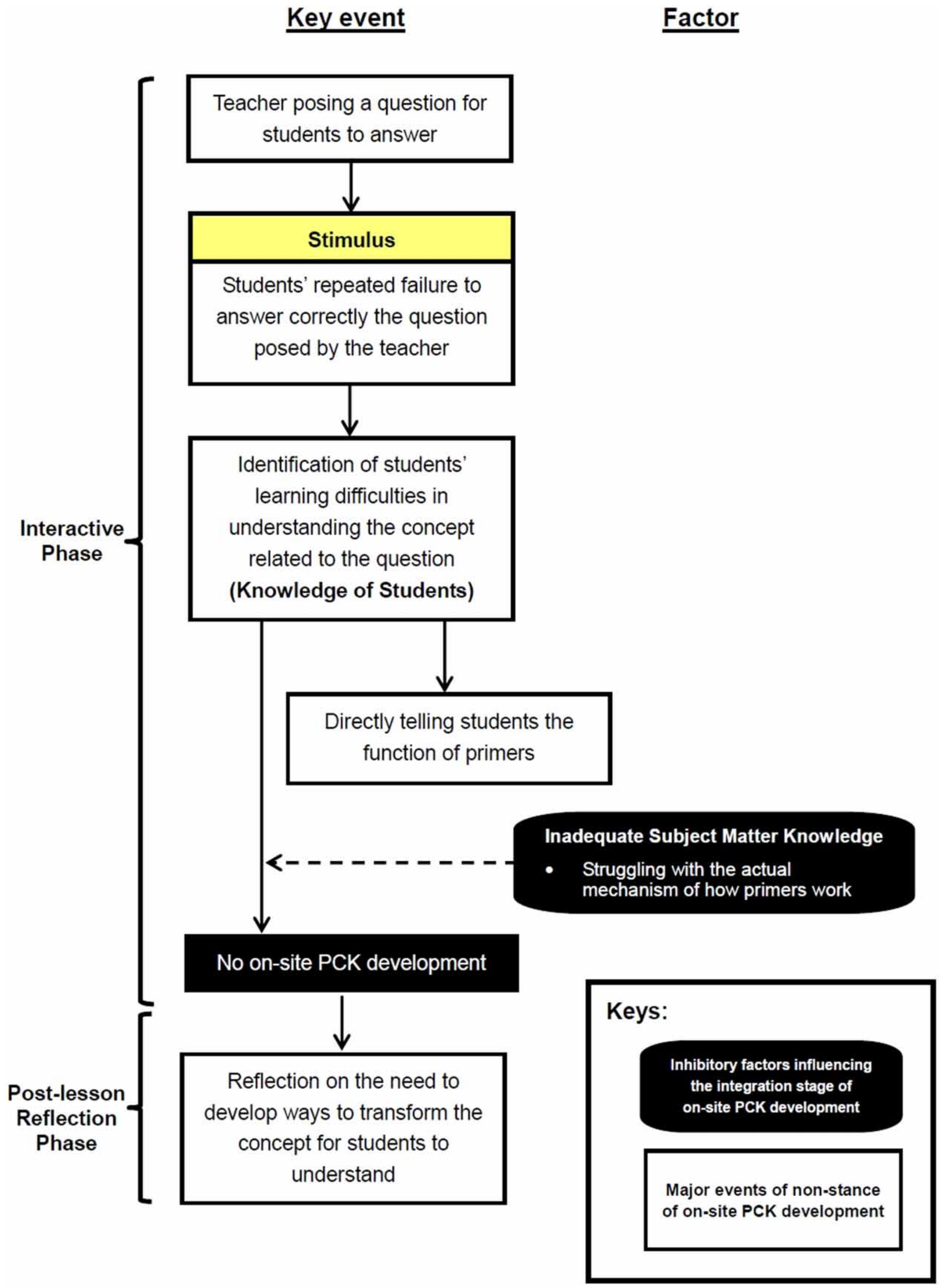

Figure 4. Dennis's non-instance of on-site PCK development in Vignette 4

during the interactive phase of the lessons when they were teaching a new and conceptually unfamiliar topic. The researchers stopped short of probing further into the phenomenon. The present study, through empirical data, not only confirms but also

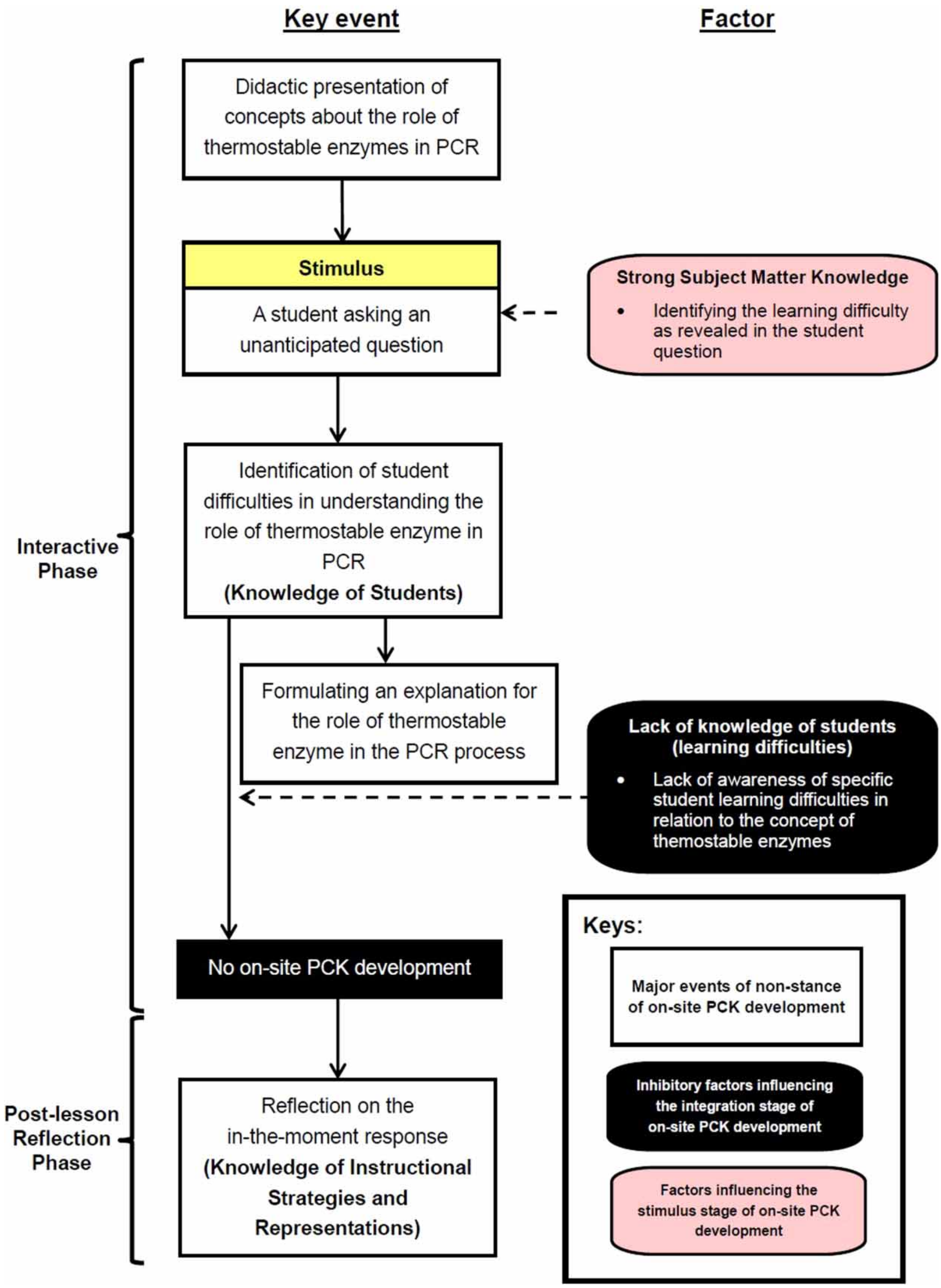

Figure 5. Chris's non-instance of on-site PCK development in Vignette 5

provides details of experienced biology teachers' capability to invent new instructional strategies/representations in the midst of a lesson. Through examination of the teachers' reconstructed thought processes associated with successful and unsuccessful instances of on-site PCK development, the current study also provides insight into the factors that may contribute to or hinder the knowledge creation process. The empirical findings regarding the stimuli (RQ 1) and factors (RQ 2) influencing on-site PCK development are summarized in the model in Figure 6. The identification of the structure of on-site PCK development (i.e. stimulus, integration and response) extends current understanding about PCK development. The three-step model advanced by the present study can pave the way for future research into the role of SMK and PK in the different phases of on-site PCK development. For example, our data suggest that both strong SMK and strong PK would allow teachers to make better sense of the stimulus. Strong SMK enabled the teacher in this study to notice the specific misconceptions of the students (Vignette 3), whereas strong PK allowed the teacher to see a nearly missed opportunity to insert a new instructional strategy (Vignette 2). We believe that more systematic research based on this model may result in the identification of salient factors that are crucial in the different phases of on-site PCK development.

While our data demonstrate that on-site PCK development could occur among the teachers, it does not mean that the instructional strategies/representations created on-site would necessarily be used again or be planned for in the teachers' future teaching of the topic. There are reasons (e.g. teachers' limited time for reflection after lessons) to envisage that the teachers may lose the strategies/representations they developed on-site, retaining just some of them. Likewise, the instructional strategies/representations teachers invented on the spot may not be ideal in terms of their effectiveness in improving student understanding Hence, it is imperative for teacher professional developers to find ways to help teachers not only to retain but also to consolidate and/or refine the PCK they develop on the fly during the their lessons. We believe that the present study, by illuminating the facilitating factors and possible mechanism involved, has shed light on a few possible ways forward in this direction.

First and foremost, to prepare teachers for on-site PCK development, it is important to nurture teachers' dispositions to pay close attention to the possible triggers of on-site PCK development such as those identified in the present study (i.e. the stimuli of on-site PCK development). One possible way to achieve such a goal is to expose teachers to critical moments (i.e. classroom moments with the potential to trigger on-site PCK development) captured using videos or written vignettes, highlighting some

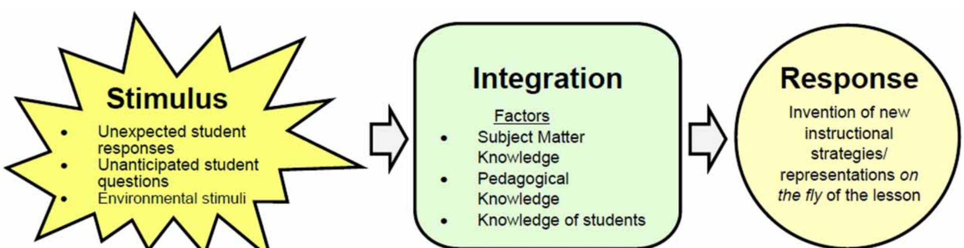

Figure 6. A model summarizing the empirical findings about on-site PCK development

often-ignored stimuli (e.g. unexpected student questions or unanticipated students' responses). This suggestion is particularly valid given that only three instances were *noticed* by the teachers as a missed opportunity to act in their Post-lesson reflection. We believe that if teachers are sensitized to these stimuli and see their novelty as a chance for them to take a new course of action they will be better positioned to capitalize on these critical teaching moments to develop new PCK instead of letting them go unnoticed. Nevertheless, recognizing a stimulus does not guarantee successful on-site invention of new instructional strategies/representations. Teachers should not only be enriched with the domains of knowledge (e.g. KS and SMK) required for on-site PCK development, they should also be afforded opportunities to closely examine and reflect on their decision-making process in their routine responses to critical moments (i.e. the integration step in on-site PCK development). As illustrated in Vignette 5, only when Chris was re-exposed to the critical teaching moment and stimulated to re-examine his responses, did he come to notice the novelty of the event and become dissatisfied with his spur-of-the-moment response. This in turn prompted him to consider a new course of action. If Chris had been helped to be more critical and aware of his habitual response towards similar critical moments, he might have refrained from direct teaching and acted differently in the moment. To achieve this goal, teachers may engage in collaborative discussion to share their own stories of encountering critical moments or be exposed to interactive video cases (Hewitt, Pedretti, Bencze, Vaillancourt, & Yoon, 2003) to elicit their personal instructional responses towards critical events. Putting teachers in a collaborative setting would allow them to make often tacit thinking processes overt. It would also afford them a chance to examine alternative courses of action offered by other teachers. This would allow them not only to imagine how they may act differently in such moments but also to reflect more deeply about their decision-making processes. In summary, in addition to equipping teachers with the requisite knowledge bases for on-site PCK development, we believe that making teachers more aware of their routine responses (and the underlying pedagogical reasoning) as well as the possible alternative ways of dealing with critical moments can better prepare teachers for on-site PCK development in their *future* encounters of similar situations.

An examination of the facilitative factors in on-site PCK development also sheds light on possible ways to help teachers refine the PCK they developed on-site (i.e. their response in on-site PCK development). As illustrated in Vignettes 1 and 2, among others factors (e.g. strong SMK and KS), teachers' preferred instructional strategies are important resources upon which they draw for on-site PCK development. Professional developers should build on teachers' existing preference for using specific instructional strategies and strengthen the relevant PK to better prepare teachers for their on-site PCK development. For instance, a teacher preferring to use analogies (like Dennis; see Vignette 1) to tackle student learning difficulties should be alerted to the limitations of using analogies to teach abstract science concepts such that the quality of PCK generated on-site would be better. In other words, consolidating the teachers' general pedagogy is a foundation for on-site PCK development.

For teachers to retain the PCK they develop on-site, they ought to recognize and value these initial ideas (i.e. their response during on-site PCK development) as valuable precursor ideas, upon reflection of which they can be further refined and developed into a substantial body of professional knowledge. Recently, researchers have provided ample evidence of the benefits of making explicit to teachers the notion of PCK, including fostering their understanding of the complexity of professional knowledge (Bertram & Loughran, 2012; Loughran, Mulhall, & Berry, 2008) as well as promoting their PCK development (Hume & Berry, 2011; Mavhunga & Rollnick, 2013). In other words, we need to make explicit to teachers that PCK is a unique province of their own, and that they are creators of their *own* PCK. We believe that the benefits of such a 'PCK approach' can be further augmented by sensitizing teachers to the concept of on-site PCK development. Indeed, researchers in the mathematics education domain have already paid close attention to how PCK is deployed in critical moments (Rowland, Huckstep, & Thwaites, 2005; Schoenfeld, 2011) and designed theoretical tools (Turner & Rowland, 2011) to help direct pre-service teachers' attention to, and reflection on, critical moments occurring in teachers' own classrooms to foster their PCK development. We believe that sensitizing teachers to the concept of on-site PCK development would also bring about similar benefits and prompt teachers to reflect on the strategies/representations they invent on-site such that these new inventions would be retained in the teachers' future instructional repertoires.

The Way Forward

As mentioned earlier, we did not set out to focus on on-site PCK development. The shift of focus was largely driven by the data as they emerged. However, this line of research deserves to be followed up and expanded using more vigorous designs. Recent advances in technology such as the advent of wearable mini camcorders (Reich, Goldberg, & Hudek, 2004) capable of capturing teachers' in-the-moment noticing (Russ & Luna, 2013; Sherin, Russ, & Colestock, 2010) may represent one possibility for this new avenue of research. Also, the instances of on-site PCK development might have been better identified by the case teachers if they had been introduced and sensitized to the concept of on-site PCK development. Although these research designs may also have their own shortcomings by being artificial in nature, these limitations should not be used as an excuse for PCK researchers to stop here. Rather, they should be seen as an impetus to think of more creative ways to pursue this line of investigation.

Several meaningful questions emerge as further lines of inquiry. For example: What is the process of on-site PCK development in the context of teaching non-canonical science content (e.g. teaching argumentation and nature of science)? How could teacher educators/professional developers help teachers to retain and consolidate the new KISR they develop on-site? In conclusion, the present study not only reinforces the maxim that experience and reflection are the foundation for PCK development (Nilsson, 2008) but also calls for more attention to be given to teachers' reflection-*in*-action of their *own* teaching experiences.

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Notes

1. In this study, we view PCK as a *separate* knowledge base transformed from SMK, pedagogical knowledge and contextual knowledge. We hence see the *inventive* process as the transformation of these parental knowledge bases into new KISR.
2. As DNA samples are colourless, a coloured dye (called loading dye) of known molecular size is mixed with the DNA sample. The coloured dye will move in the electric field allowing the monitoring of how fast a negatively charged chemical species moves in the applied electric field. This in turn allows the tracking of the movement of the DNA samples.

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Appendix A: Interview protocols

Post-lesson Interview:

(1) How do you feel about the lesson?
(2) Did any unplanned incidents/unanticipated moments happen in the lesson? If so, why?
(3) You used (an animation, picture and analogy) to help students learn … . Why? Are there any particular reasons for the use of this (strategy) for teaching?

Stimulated Recall Interview:
Say to the participant: I will show you several video clips on your teaching of the lesson (s) on the topic PCR. They aim to recap your memories. I will be asking you some questions related to each video episode after we have viewed the video together. If you have anything you want to comment on the videos, feel free to stop and comment on the episode.

Show the video.

(1) What concept(s) related to the topic PCR did you want to bring out from this teaching and learning activity?
(2) Was this activity/instructional strategy planned? How did you come up with that idea?
(3) What is your pedagogical decision of using this activity in teaching this concept? In what way is this strategy particularly useful in helping students to learn the (PCR) concept(s) you want them to understand?
(4) Have you thought of any other ways to bring out this key concept?/ Have you considered organizing the classes in a different way? If so, why didn't you choose the alternative ways?
(5) Overall, do you think this activity worked well in achieving its planned objective (s)? Are you satisfied with the activity? Why?
(6) Will you use the same activity in your next round of teaching? Why or why not? If yes, how would you modify this activity in your next round of teaching?
(7) Is there anything you want to say about this episode?

Appendix B: Coding categories for PCK_{PCR}

Knowledge of instructional strategies and representations	Knowledge and understanding of topic-specific activities and representations. Representations can be, but not limited to, examples, models, illustrations and analogies Activities can be problems, examples, demonstrations, simulations, experiments and many others
Knowledge of students	Teachers' knowledge and understanding of the prerequisite knowledge for learning and the variations in approach in learning Teachers' knowledge and understanding of what students know about a topic including students' difficulties in learning and misconceptions
Knowledge of curriculum	Teachers' knowledge and understanding of goals and objectives of the curricula (including prior curricula (i.e. HKCEE and HKDSE) as well as other subjects (i.e. chemistry and physics)), both vertical and horizontal Teachers' knowledge and understanding of the programmes and materials (including the three sets of NSS textbooks) relevant to meeting the curriculum goal
Knowledge of assessment	Teachers' knowledge and understanding of the dimensions of science learning that are important to assess Teachers' knowledge and understanding of the methods by which that learning can be assessed

General rules in coding: modified from Gardner and Gess-Newsome (2011)

- It is assumed that the teachers' use of language can reflect the accuracy of his understanding. The actual assessment of the PCK knowledge possessed by the teachers was based on the *actual evidence* not on assumption.
- Teacher's responses to the questions and *their rationales for the observed steps in the classroom procedures* should be the main determinant of the PCK knowledge possessed by teachers rather than 'what the teacher does/students do'. For example, if a teacher happens to have elicited the prior KS/to have used an instructional strategy, but his/her rationale does not indicate that this was the purpose, it is not counted as such.

Knowledge of instructional strategies and representations

- Do not count 'examples' unless the teacher explicitly explains how the example *can aid students' understanding of the concept(s)*. Analogies should be counted as examples only *if the teacher connects them to the relevant concept(s)*.
- Do not count instructional strategies/representations unless the teacher explicitly explains how the instructional strategies/representations can aid students' understanding of the concepts and *connects the strategies to the relevant concept(s)*.

Knowledge of students

- Do not count KS if it is *a conjecture* of the teacher (e.g. may and probably)

- Do not count 'prior knowledge' unless the teacher states explicitly the concept(s)/ idea(s) the students learnt before.

Knowledge of curriculum

- Count knowledge of curriculum when the teacher *mentions about the topic students learnt before* in previous year or in other subjects/the (HKALE/HKCEE/HKDSE) syllabus
- Count as knowledge of curriculum when the teacher explicitly mentions about some particular information related to the concepts in the textbook(s)

Knowledge of assessment

- Do not count knowledge of assessment unless the teacher *explicitly identifies the parts as such* (e.g. using words such as 'assess', 'check understanding/prior knowledge' and 'diagnose prior knowledge/incoming ideas/misconceptions'). In that case, the classroom transcripts and the assessment materials should be read to triangulate the data and to determine teachers' knowledge on 'what to assess' and 'how to assess'.

Appendix C: PCK reporting table for Vignette 1

Teacher	Dennis
Lesson	Lesson 1
Theme	(5) Uses and Applications of PCR
Vignette	A. Uses of PCR
Analysis	

What did the teacher do?	**Data Sources**
After a hands-on activity (Who stole the tortoise?) about DNA fingerprinting with students in the first lesson, Dennis questioned students the problem of working with one molecule of DNA in DNA fingerprinting. He raised an analogy and drew a diagram on the blackboard to illustrate the problem of 'invisibility' of a small quantity of DNA during DNA fingerprinting analysis. After that he went on to explain the role of PCR in DNA fingerprinting (an example of application of PCR)	Observation Field notes Lesson transcript Post-Lesson Interview Stimulated Recall Interview Classroom artefact (PPT, photograph)

Description of student–teacher interaction

Dennis was getting a DNA paper model form one of the students

D:	Now I assume that it is just that much (of DNA)
D:	If you really perform DNA fingerprinting analysis. In your view, how would this (i.e. small amount of DNA) affect you?
D:	Now it is just that much (of DNA), just one molecule (of DNA)
D:	What is the problem? Would you be limited (by such a small amount of DNA)?
S1:	Probably, the others also have that (DNA). That is, two people may also have these DNAs (which are the same). You have only done (analysis on) this strand (of DNA only)
D:	Yes. Correct. Probably, both people have that (DNA). If both have (the same type of DNA), it (the DNA) is just that short …

D: Probably, it (the resolution) is not enough. This is the insufficiency of resolution. The degree of variations among one person and the other is not sufficient (for differentiation). This (concept) will be later mentioned
D: Anymore? Any more problems? Just now our classmate mentioned the problem of tandem repeats, how about the problem of quantity?
The students looked confused
D: How about the amount of DNA? This is just that much (of DNA)
D: If you put it (the DNA strand) into the (gel electrophoresis) machine, do you think that you would be able to see it after it (the machine) runs? It is just that much (of DNA)
D: Only one molecule (of DNA), can you see it?
Ss (It) can't be seen
D: Imagine a situation. There is a cell. There is only one cell, can you see it?
D: Previously, I taught you how to grow bacteria, right?
Dennis was drawing the image of a culture plate on the blackboard
D: Now, we have inoculated some bacteria
D: [The bacteria] can't be seen [now]. When will you be able to see the bacteria?
S2: When they grow in number to form bacterial colonies
Dennis was adding some bacterial colonies on the diagram he drew

D:	Yes. When they turn into bacterial colonies!
D:	Yes. When they (the bacteria) turn to bacterial colonies. Yes
D:	What process do they (the bacteria) need to go through to become bacterial colonies?
Ss:	Reproduction
D:	Reproduction
D:	They (the bacteria) need to divide and replicate (to large quantities). Then, you would be able to see each (of the bacterial colony) appearing individually. Right?
D:	Now, we have the same situation. The problem is. Now you practically just have that much (of DNA) –one molecule of DNA
D:	Now, the same situation we have is like that
D:	It is really so unlucky that you have just isolated one single molecule of DNA
D:	When you have performed analysis in DNA fingerprinting, are you able to see [the DNA]?
Ss:	[The DNA] can't be seen.
D:	After you have done the (DNA fingerprinting) analysis, the DNA can't be seen, right?

Students nodded their heads. Dennis then went on to introduce the function of PCR in amplifying the DNA for DNA fingerprinting

Evidence of the presence of PCK components identified in the episode	**Data sources**
I remembered that at that time, I mentioned that there was just one molecule (of DNA). They were not able to get it (the concept). … To help them understand (the concept) that with only one molecule (of DNA), I can't see my DNA band (in a stained agarose gel) and that I would have to find ways to make it (the DNA) visible, I therefore need to use this method (PCR) to copy it (the DNA) in large quantities for it (the specific DNA) to be visible … . I immediately came up with it (the diagram) … because I believe that to let them (students) understand that with one molecule of DNA, I can't see (the DNA band on stained agarose gel), I used this (analogy). … My memory on teaching them the topic Transgenic Organisms just flashed in my mind, I talked about bacterial colonies. So, they would be able to associate this (concept) with that (the analogy) (Post-lesson Interview #1) (Knowledge of Instructional Strategies, Knowledge of Curriculum, Knowledge of Students; concept addressed) Initially, I expected that when I say that there is only 1 molecule (of DNA), it can't be seen (in a stained DNA gel). I had expected that they would easily understand. But I believe that, when we were running gel, we just loaded (the DNA) and then we could see (the bands). That is, they won't know that the bands consist of a lot of DNAs. … (Hence,) they would think that, even with one molecule, it (the DNA) will be stained. They think that it (one molecule of DNA) is also visible. … Initially, I expected that that would be a relative easy question for the students. But then, they really couldn't come up with the answer to my question. … . I then used that analogy. … I was thinking about the replication of cells. The concept of replication is also applicable to bacteria. It is the same as the replication of DNA in PCR. … Then, let's use bacteria. (Multiplication of) bacteria (to form bacterial colonies) also involves the concept of replication. It is the same as the replication of DNA. So I think that this analogy is good, then I use it. (Post-lesson Interview #1) (Knowledge of Instructional Strategies, Knowledge of Students; concept addressed)	Observation

First, I want to help them link up relationship with (the topic) DNA replication, when teaching PCR. They have learnt the concepts about (the process of) DNA replication before. Second, I also want them to know that for every technique, there is a reason why this technique is developed. … I want them to first learn what the use of the technique is and then to learn how the technique is done. (Stimulated Recall Interview) (Knowledge of Curriculum, Knowledge of Students)				Field notes Post-Lesson Interview Stimulated Recall Interview
PCK components integrated in the episode				**Data sources**
Knowledge of students	Knowledge of instructional strategies	Knowledge of assessment	Knowledge of curriculum	Observation Field notes Lesson transcript Post-Lesson Interview Stimulated Recall Interview Classroom artefact (PPT; photograph)
✓	✓		✓	