# A Thai Physics Teacher's Conceptual Difficulties While Teaching Unfamiliar Content

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## Abstract

This paper reports on a case study that investigated conceptual difficulties experienced by one physics teacher teaching unfamiliar content in a Thai high school and the consequent effects on her pedagogy. Naturalistic inquiry data collection methods including classroom observation, teacher interview, and examination of instructional materials were employed. Using a sociolinguistic perspective along with a communicative approach, critical incidents related to the case teacher's limitations in conceptual knowledge were identified and analyzed. The study's results included the case teacher's impetus view of force and some partial understandings of physics concepts as causes of her difficulties in discerning key ideas of taught content, inability to recognize student learning problems, inappropriate guidance of student learning, and inability to sustain classroom discussion. This study therefore argues for ongoing science teacher pedagogical and content knowledge appraisal in the context of teacher professional development.

**Keywords:** Content Knowledge, Education Reform, Physics Teacher, Teacher Development

## Introduction

Science education reform in Thailand has been ongoing since the promulgation of the 1999 National Education Act (Office of the National Education Commission [ONEC], 1999). Central to this reform policy is the desire to change from the traditional teacher-centered to student-centered instruction (ONEC, 2000a). Underlying this instructional change is the expectation that students will learn key science concepts more authentically in order to become scientifically literate citizens (Institute for the Promotion of Teaching Science and Technology [IPST], 2002; Yuenyong & Narjaikaew, 2009). Hence, there has been a push to have Thai science teachers implement a variety of instructional approaches (such as inquiry-based, hands-on minds-on, problem-based, and cooperative instruction), which

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are framed from constructivist perspectives of knowledge acquisition (Dahsah & Faikhamta, 2008).

Despite tremendous efforts made in this regard, many Thai science teachers still find it difficult to implement student-centered instruction in ways consistent with constructivist perspectives as demanded by the education reform policy. The teachers have pointed to their own limited content knowledge as a primary obstacle (Magrood-In et al., 2009; Pongsophon & Roadrangka, 2004; Soparat et al., 2007; Sreethunyoo & Yutakom, 2007). This is also evidenced by various empirical studies (Bongkotphet et al., 2009; Chamrat & Yutakom, 2008; Jantaraprasert et al., 2008), which have particularly revealed Thai science teachers' problems related to their content knowledge (e.g., alternative conceptions). However, very few studies (Kijkuakul et al., 2008) try to articulate conceptual difficulties experienced by Thai science teachers while teaching content which they are unfamiliar or inadequate. Without a better understanding of this, it could be a wild expectation that Thai science teachers with limited content knowledge will change their traditional instruction to be more student-centered.

According to Shulman (1986), content knowledge can be defined as "the amount and organization of knowledge in the mind of teachers" that includes knowing "facts or concepts" as well as "understanding the structure of the subject matter." The structure of the subject matter is about ways in which content is organized within the discipline and how it relates to other disciplines (substantive aspects) and about how content is acquired and enacted as a discipline (syntactic aspects). Syntactic aspects might include "values and assumptions inherent in the development of scientific knowledge" (Lederman, 1992), which is commonly referred to as the nature of science. Content knowledge is perceived as a prerequisite for effective science instruction (van Driel et al., 1998). It can influence teaching practice of science teachers in a number of ways.

Content knowledge influences teachers in deciding what to teach, to what extent, and how particular content might be taught. Carlsen (1991a) noted that teachers tend to spend more time teaching familiar topics than unfamiliar ones. Gess-Newsome and Lederman (1995) reported teachers with well-structured content knowledge as being able to specify scope and sequence of content to be taught, without relying heavily on textbooks. When given a textbook, content-rich teachers can decide what content to add or delete based on their content knowledge, as they know the important content in curriculum for students to learn, while teachers with inadequate content knowledge have difficulties making similar decisions (Hashweh, 1987; Kapyla et al., 2009). Thus, teachers with strong content knowledge are more likely to be selective in terms of what is meaningful for students to learn than teachers with inadequate content knowledge.

Besides, teachers' content knowledge may relate to their use of instructional strategies (Carlsen, 1991a). According to Lee (1995), teachers with limited content knowledge tend to keep students working individually on worksheets with a minimum contact in order to conceal their weak content knowledge. Content knowledge might also relate to nature and frequency of questions a teacher poses to students and how he/she responds to students' questions (Newton & Newton, 2001). Teachers with strong content knowledge are more likely to be aware of students' alternative conceptions and deal with those conceptions more effectively than teachers with weak content knowledge (Hashweh, 1987; Kapyla et al., 2009). Also, it is more likely for content-rich teachers to exploit opportunities unexpectedly occurring in classrooms (e.g., student questions) to continue the instruction in productive ways (Sanders et al., 1993).

With regard to the important roles of content knowledge on science teaching, we are concerned with how physics teachers with limited content knowledge conduct their class in order to effectively promote student learning. Thus, in this current study, we aim at investigating conceptual difficulties experienced by a physics teacher (pseudonym used as Mrs. Darika) who has to teach content with which she is unfamiliar. As part of physics teacher development research, we want to better understand her difficulties related to content knowledge, and consequently, facilitate her to overcome those. Equally important, understanding her difficulties due to limitation in content knowledge could provide critical insights to the teacher development process in Thailand.

## Methodology

To investigate conceptual difficulties experienced by Mrs. Darika while teaching unfamiliar content, naturalistic inquiry (Lincoln & Guba, 1985) was employed in order to collect data from her classroom. In doing so, a sociolinguistic perspective (Carlsen, 1991b) was used to interpret verbal interactions among Mrs. Darika and her students in regards to context, content, and status differences. A communicative framework (Scott et al., 2006) was also applied to characterize the nature of their classroom discourse. More specifically, "critical incidents that occurred while teaching" (Hashweh, 1987) which represented Mrs. Darika's limitations in content knowledge, were focused on for detailed analysis.

*Context of the Study*

Mrs. Darika teaches in a suburban, science-emphasizing school with a population of approximately 1,150 students. The school consists of 30 classes (15 in the lower secondary level and 15 in the higher secondary level), in which the number of students per class in each level are limited to 40 and 36 students respectively. There are 65 teachers, which include 16 science teachers (10 females and 6 males) in the school. Mrs. Darika is one of 5 physics teachers (2 females and 3 males).

The school is very supportive in terms of facilities provided to its teachers and students. Many classrooms are equipped with air conditioners, television sets, and overhead projectors. Laboratory equipment, artifacts, and materials are adequate for all students to work together in groups of 4-6. In addition, there are laboratory boys/girls who prepare and maintain the laboratory equipment for any science teacher and work as teaching assistants, if requested, during class hands-on activities.

*The Case Teacher*

Mrs. Darika was 52 years old with a bachelor's degree in physics teaching. Despite having earned this degree, she had taught chemistry- and biology-related content in the lower secondary level for 26 years. During the 26 years of being out-of-field, she became more familiar and competent with chemistry and biology content. As a result of her hard work as a lower secondary teacher, Mrs. Darika earned an academic position as a specialist teacher[i].

Until Mrs. Darika moved to the present school in 2003, she was shifted from teaching lower to higher secondary level, in which she returned to

*[i] According to ONEC (2000b) teachers in Thailand can be classified into four levels (i.e., teacher, senior teacher, specialist teacher, and senior specialist teacher), which relate to their maximum level of salary. To upgrade his or her level, a teacher has to do and submit some academic work (e.g., conducting classroom research and developing instructional innovation) to be assessed by educational scholars. Mrs. Darika is one of specialist teachers in the province who achieve at the third level.*

teaching physics. However, long experience teaching out-of-field content had made her physics background untouched, so she was uncertain about in-field content. As a consequence, she declared herself as an unknowledgeable teacher in physics and volunteered to participate in this study with the intention of improving her content knowledge for effective instruction.

During the time of this study (the first semester of the 2008 academic year), Mrs. Darika taught 3 classes of grade 10 physics, 1 class of grade 11 science projects, and non-science subjects (Boy Scouts and homeroom), resulting in an overall teaching load per week of 16 periods. Besides teaching, she was responsible to keep records of equipment/material used in the school. During the last two years, she attended a professional development program about doing classroom research. As a highly-respected, specialist teacher, she was selected by the school district to assess classroom research done by other science teachers.

*Classroom Context*

This study involved one of Mrs. Darika's grade 10 physics classes. The class had 36 students (25 females and 11 males) and met for four 50-minute periods a week. Throughout the semester, they worked in mixed gender groups of 4-6. The topics covered included one-dimension motion, Newton's laws of motion, friction, mechanical equilibrium, and simple machines. The students had a good rapport with Mrs. Darika, who also was their advising teacher. They were actively engaged in classroom discussions where they asked questions freely. Nevertheless, according to Mrs. Darika, during vacation most of them had private tutors and developed an affinity for content "feeding." As a consequence, they expected her to also feed them with content knowledge.

Although Mrs. Darika employed various activities (lecture, demonstration, classroom discussion and experiments), they were predominantly content-driven with an emphasis on numerical physics problem solving. Her verbal interactions with the students could be best characterized as unidirectional, which according to Scott et al. (2006), was a shift between an *interactive/authoritative* and *a non-interactive/authoritative* approach. In other words, she focused only on the physics point of view (e.g., definitions, explanations, and formula) with and without student interaction respectively. Only once, when an issue needed more careful exploration, did she consider a range of the students' ideas–*interactive/dialogic* approach–in order for them to reach a shared conclusion.

*Data Collection*

The primary data of this study were collected through regular classroom observations in the target class selected by Mrs. Darika. From July to September 2008, six 2-period classroom observations were undertaken in non-evaluative manners. All classroom observations were audio- and video-recorded with Mrs. Darika's permission for reviewing, transcription, and analysis. Copies of instructional materials were also collected and examined. However, neither lesson plans nor student work were available.

Semi-structured interviews regarding Mrs. Darika's views on good science teaching, views on the nature of science, and past experiences as a learner were conducted as supplementary for making interpretation of her classroom actions. Most of the interviews were audio-recorded except informal conversations, where Mrs. Darika reflected on her teaching (mostly occurring at lunch time). However, the researchers noted key ideas of the conversations in their field notes.

*Data analysis*

Classroom observations and interviews were transcribed verbatim. Critical incidents that represented Mrs. Darika's limited content knowledge were identified and coded by reading through video, audio, and field notes transcripts, and reviewing video clips back and forth. Initially, as guided by Shulman's (1986) interpretation of content knowledge, three aspects regarding conception, organization, and the nature of science were considered, producing 20 incidents overall. However, since the data from classroom observations were limited while the "organization" and "the nature of science" aspects needed a further probe, only 15 incidents regarding the "conception" aspect, which is most striking, were selected for detailed analysis. Transcripts of the selected incidents were read and reread in order to derive patterns of Mrs. Darika's conceptual difficulties. Triangulation among the incidents as well as supplementary data were used to confirm or question the patterns derived. Peer debriefing was also used to revise the patterns.

## Results

In this section, Mrs. Darika's conceptual difficulties while teaching unfamiliar content (physics) are presented in two parts. First, her *limitation in conceptual knowledge* is analyzed by comparing her views with canonical physics. Second, apparent *difficulties during teaching* (during facilitating of student learning) are illustrated.

*Limitation in conceptual knowledge*

Mrs. Darika conceptual knowledge of force as a concept in high school physics was shown to be limited as it became apparent from our observations in her classroom. Most strikingly, data from the six classroom observations show that Mrs. Darika holds an impetus view of force when she explained an object's instant velocity at the highest position to the students as follows:

It (object) goes like this (vertically moving up into the air). When its force is gone, it would then fall down. At this (highest) position, it has no force–the force we threw. [July 23, 2008]

The phrases like "its force is gone," "it has no force," and "the force we threw" imply that Mrs. Darika conceptualizes force as something (so-called an impetus), which is imparted from hand to the object. During the upward motion of the object, the impetus then dissipates due to the air resistance until it is gone at the highest position. Once there is no the impetus, the object begins to fall down to the ground. Halloun and Hestenes (1985) describe this view conveyed in expressions such as: "When an object is thrown, the active agent imparts to the object a certain immaterial motive power which sustains the body's motion until it has been dissipated due to resistance by the medium." This un-canonical view of force was evident in Mrs. Darika's instruction. Other sentences that represent Mrs. Darika's impetus view of force were also communicated to the students as follows:

- (Force is) a power or an attempt that makes an object move. [*August 4, 2008*]
- If we give it (force) more, can it (a cart) move a longer distance? *[August 4, 2008*]
- The Earth can orbit the sun because each one sends a force to attract each other. [*August 11, 2008*]

To clarify this problematic view of force, Brown (1989) argues that force, in a physics point of view, should be conceptualized as an interaction between a pair of objects rather than a power or acquired property that makes an object move. Chi et al. (1994) also support this conceptualization, suggesting that force should be ontologically classified as *Process*–that is, an interactional process between two objects–instead of Matter in which the impetus tends to be positioned. Thus, Mrs. Darika's conceptualization of force as the impetus can be considered as an ontological misclassification[ii] (see Chi et al., 1994).

Besides the impetus view of force, which is based on or resulting from everyday-life experience, there is evidence indicating that Mrs. Darika has partial understandings of other related concepts such as friction, mechanical equilibrium, and motion. These partially canonical understandings could have resulted from her personal interpretations of physics content. Some of the incomplete understandings exhibited included:

- Kinetic friction occurs when an object is moving with constant velocity. [*September 1, 2008*]
- Rotational equilibrium must be no rotation. [*September 8, 2008*]

Generally, the above incomplete expressions depict incomplete or partial understandings as communicated to the students when Mrs. Darika was lecturing ignored some specific but important conditions. For example, kinetic friction can also manifest between objects with non-constant velocity and rotational equilibrium also includes rotation with a constant angular velocity. It is important to note that ignoring such conditions may not be intentional since, in certain circumstances (time and context), they may be irrelevant. Nonetheless, it is important that students are made aware of this. For instance, there was an instant when Mrs. Darika was lecturing while the students were doing an experiment about friction and she never offered the condition that kinetic friction can occur when an object is moving with non-constant velocity.

Mrs. Darika's partial understanding was also evident when she conducted numerical physics problem solving. For example, in a number of situations such as the force acting on a man stands in a lift moving vertically, she explained to the students that "the normal force (that the ground of the lift acts on the man) is always up and the weight (of the man) is always down" [*August 11, 2008*]. Although this sentence is effective in terms of teaching the students to solve physics problems successfully, it is of course not scientific and only applicable to some "common" situations (e.g. a lift's vertical motion with acceleration less than gravity). When faced with a particular situation that the lift is moving down with an acceleration greater than gravity, Mrs. Darika seemed to have encountered difficulty in understanding why the normal force acting on the man is downward (as shown by the students' calculations). In other words, she was unable to apply her physics knowledge to a variety of situations, reflecting her limited conceptual knowledge.

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[ii] *As a theory of conceptual change, Chi et al. (1994) propose three primary ontological categories including Matter, Process, and Mental States in order to explain why conceptual change of science concepts such as force, heat, and electricity is so difficult to occur. They argue that learning those science concepts requires conceptual change across the categories (i.e., from Matter to Process), which have distinct attributions. That is, force must not be conceptualized as a kind of substance that an object possesses and consumes, but a kind of interaction between two objects. They also argue that students who still conceptualize force as matter or substance "can never achieve complete understandings of the concept unless they...assimilate[e] the...concept into a different ontological (category)" (p. 34). For related reading, see also Reiner et al.'s substance schema (2000).*

*Difficulties during teaching*

To illustrate and discuss Mrs. Darika's conceptual difficulties while teaching, incidents of verbal interactions between Mrs. Darika and her students is sequenced numerically in each case of: *difficulty in capturing the key idea of content being taught; difficulty in guiding student learning towards the target content; and difficulty in maintaining classroom discussion.*

*Difficulty in capturing the key idea of content being taught*

Since Mrs. Darika did not conceptualize force as an interaction between a pair of objects but rather as the impetus, she encountered difficulty in capturing the key idea of the content being taught, in this case, Newton's third law of motion. While teaching this topic, Mrs. Darika used the example of a spring balance hooked on to her finger. However, instead of emphasizing the idea of interaction between the objects (spring balance and finger), she spent a lot of time trying to identify which force was the action or reaction:

| | | |
|---|---|---|
| 1. | Mrs. Darika: | Which one is action? |
| 2. | Student: | Your finger is acting on the balance. |
| 3. | Mrs. Darika: | Which one is the reaction? Since you say that my finger is the action, in which direction is my finger acting? Up or down? |
| 4. | Students: | Up; Upward. |
| 5. | Mrs. Darika: | Up. Then, what is the direction of the reaction? |
| 7. | Student: | Downward. |
| 8. | Mrs. Darika: | What is this force called? |
| 9. | Students: | Weight.<br>The pencil bag.<br>[*August 11, 2008*] |

As shown in the above excerpt, Mrs. Darika failed to make a distinction between the force that acts on the object and the object itself. Obviously, she misinterpreted a student's response by saying that "my finger is the action" (# 3). According to Chi et al 's. (1994) ontological classification, the finger (object) should be classified into the *Matter* category while the action (force) should be classified into the *Process*. However, Mrs. Darika tended to link these two incompatible categories together, showing that she might not be aware of the difference in their ontological attributions. Furthermore, her unconscious ontological misclassification led the students to be confused with the ontological attribution of force since they referred to it as "weight" (Process) and "pencil bag" (Matter) (# 9).

Though important, identifying which force is action or reaction did not seem to create a meaningful discussion since it was dependent on which of the objects (spring balance or finger) was shared as reference by Mrs. Darika and the students. Without a shared reference, the discussion became very confusing. Furthermore, Mrs. Darika seemed unaware of what made it confusing even though she tried to identify the direction of each of the forces. In this case, the key idea of Newton's third law of motion that force is an interaction between two objects (Brown, 1989) was either ignored by Mrs. Darika or reflected her lack of understanding. Her comments seem to suggest a weak conceptual understanding of Newton's third law of motion, which made it difficult for her to explain this concept to her students. Without strong conceptual knowledge of Newton's third law of motion, it seemed difficult for Mrs. Darika to capture its key idea. It seemed even more difficult for her students to conceptually understand Newton's third law of motion.

*Difficulty in guiding student learning towards the target content*

In addition to the difficulty in capturing the key ideas of the content being taught, Mrs. Darika's conceptualization of force as the impetus, due to the ontological misclassification, created difficulty for her in guiding students' learning towards the target concept. This was evident when she introduced the concept of normal force. By way of demonstration, she dropped two identical pieces of plasticine from different heights, and then initiated a discussion with the students regarding the cause of the plasticine's shape change:

1. Mrs. Darika: Tell me, which piece dropped from 50 centimeters and which piece dropped from 200 centimeters? The one on my left or right hand?
2. Student: Right.
3. Mrs. Darika: This group answered right. Why?
4. Student: It was falling from 200 centimeter height.
5. Mrs. Darika: How do you know that this one was dropped from 200 centimeter height?
6. Some students: (The plasticine's) shape was changed.
   Force.
   There is a force acting (on the plasticine).
7. Mrs. Darika: You answered force? Whose force?
8. Some students: Gravity.
   The Earth's gravity.
   Force that acted on the plasticine.
   The Earth's force.
9. Mrs. Darika: Why don't you think that the ground acts as a force on it (plasticine)? Doesn't the ground exert force?
   [*August 4, 2008*]

At the beginning (# 1-6), the discussion seemed productive and moving towards the target concept of normal force since the students were able to appreciate that there was a force acting on the plasticine and that made its shape change. However, what was challenging for them was to identify the *unknown* force that made such a change. Many of them assumed gravity was the cause of the change in the plasticine's shape (# 8), which was contradictory to canonical physics. Furthermore, some of them tended to understand gravity as an impetus imparted from the Earth to the plasticine, saying "the Earth's gravity" or "the Earth's force." Even when challenged by Mrs. Darika (# 9), none of them believed that "the ground acts as a force." Similarly to students in other contexts (Minstrell, 1982), Mrs. Darika's students had difficulty in appreciating the presence of normal force, which affected the change in the plasticine's shape.

In an analysis of this classroom discussion, instead of being aware of the students' learning difficulty, Mrs. Darika asked a question, "Whose force?" (# 7), which again implied her ontological misclassification of force. Her question implied an expectation of "something," which originally belonged to the force which was then imparted to the plasticine as substantive, rather than force as an interaction between something and the plasticine. In other words, her ontological misclassification of force led her to misguide the students to interpret the change as due to the Earth imparting its force to the plasticine, not as an interaction between the Earth and the plasticine. Rather than guiding the students towards the canonical science, Mrs. Darika's question instead appeared to reinforce an impetus view of force and the ontological misclassification for the students.

*Difficulty in maintaining classroom discussions*

Similarly to the case teacher in Kijkuakul et al.'s (2008) study, due to limitations in content knowledge, it is evident that Mrs. Darika sometimes experienced difficulty and lost confidence in maintaining classroom discussions, particularly when she was challenged by some students' questions on content that she was unsure of. For example, there was an incident where she demonstrated how to solve a physics problem involving a beam that immediately changed status from rotational equilibrium to disequilibrium. Two students asked her a question about the procedure she had used in solving the problem because they had employed a different procedure and got a different answer. Although Mrs. Darika initially encouraged all students to analyze and discuss what could bring about different answers, she instead ended the discussion abruptly when she (and the students) could not explain the difference. In our follow up informal discussion about this incident, Mrs. Darika said, "I still believe that my procedure was correct. But, I did not know how to challenge those two students' responses [September 8, 2008]." As a consequence, at that teaching moment, she resorted to traditional strategies of class control, assigning the students to do a worksheet and lecturing on another topic in order to continue instruction. Obviously, Mrs. Darika's partial understanding of rotational equilibrium hindered her ability to productively maintain classroom discussion.

## Conclusion and Discussion

This case study has demonstrated that a physics teacher who has limited canonical understanding of physics will unknowingly pass those ideas to her students and, where the students seek deeper understanding, such a teacher falls back to extreme teacher-centered strategies. For example, Mrs. Darika's impetus view of force and partial understandings of equilibrium intimidated her into ending what could have been a fruitful student-teacher discussion. Theoretically, she tended to conceptualize force into a *Matter* instead of *Process* ontology (Chi et al., 1994). This uncanonical view of force is similar to that held by pre-service Thai physics teachers reported in Buaraphan et al.'s study (2006). Buaraphan et al. (2006) claim that participating pre-service physics teachers had traditionally studied physics through a lecture-based approach that accentuated memorization of force and motion equations rather than understanding, and as a result, the pre-service physics teachers' impetus view of force remained unchallenged until they enrolled in education courses. From the current study, it would appear that the case of Mrs. Darika parallels the results from Buaraphan et al.'s (2006) study.

Adequate content knowledge held by any science teacher is a necessary component of effective science instruction (Magnusson et al., 1999; Shulman, 1986; van Driel et al., 1998). Mrs. Darika, who has inadequacies in this regard, struggles to achieve her intended instructional goals in significant ways. First, she had difficulty in capturing key ideas of the content being taught (e.g., Newton's third law of motion). The result was very limited classroom discussion and, in some cases, the target content was treated superficially or discussion abruptly discontinued. Second, she was unable to discern student learning problems, which may have parallel to her own. For example, her students shared the impetus view of force. As a result, it was not possible for her to challenge and change the students' views towards a canonical physics. Third, and perhaps crucially, Mrs. Darika tended to misguide student learning towards her problematic view of force. Typically, all this happened unconsciously for Mrs. Darika, which is a concern that has been acknowledged in science education literature in Thailand (Bongkotphet et al., 2009).

Noticeably, Mrs. Darika's limited content knowledge could affect her instruction. For example, while she encouraged the students to find what could make differences in answers of the same problem about rotational equilibrium, it was apparent that she was not confident to engage in discussion with students after they sought clarification on the difference between their answer and hers (Newton & Newton, 2001). Once she felt challenged and unable to provide satisfactory justification for her answer, which she claimed was the correct one, Mrs. Darika resorted to traditional strategies of class control as well as changing to other (more familiar) content in order to avoid exposing her limitation in content knowledge. From this significant event, it may be assumed that limitations in content knowledge as perceived by Mrs. Darika herself possibly conserved the traditional instructional approach (Lee, 1995). However, this should not be generalized to other science teachers. Since effective science instruction requires other domains of knowledge (Magnusson et al., 1999), the conservation of traditional instruction could not only have resulted from limited conceptual knowledge. Further research that investigates Thai science teachers' limitations in conceptual knowledge along with their instruction in real classrooms is needed.

## Implication to Teacher Development

This case study has demonstrated that, despite attempts to adopt student-centered approaches (such as student-teacher discussion) to physics teaching, a physics teacher with limited content knowledge will encounter difficulties in attempting to facilitate instructions that have the potential to enhance conceptual understanding. This can not be underestimated since other science teachers who are aware of their limitations in content knowledge may experience similar difficulties. For effective science instruction, it is necessary for science teachers to have adequate content knowledge to effectively undertake mandated instructional approaches. Hence, before mandating science teachers to implement a particular instructional approach, attention needs to be paid to problematic aspects of their content knowledge by offering/providing professional development programs where they can upgrade their pedagogical as well as content knowledge. Without this attention, despite tremendous efforts and budgets, the intention of reforming science education in Thailand may not be realized.

What should be done to facilitate science teachers to overcome their limitations in content knowledge? Simply telling the teachers to change in professional development workshops may not be enough since they will "continue to be dependent on the facilitator for their development" (Bell & Gilbert, 1994). Given the fact that individual science teachers' content knowledge changes over time as they gain more experience in teaching that content (Gess-Newsome & Lederman, 1995), it is crucial for them to reflect upon the instructions they implemented and critically discern some problematic aspects in their instruction. As we have been doing, this reflective activity can be initiated by questions. For example, from this study, what did Mrs. Darika mean by asking, "Whose force?" And, in Mrs. Darika's view, how was that question alternatively interpreted and understood by the students? Reflecting on implemented instruction based on students' subsequent interactions could provoke science teachers to think more carefully about their own content knowledge. Collaboratively, this reflective activity can involve a group of teachers who share a common interest or teach the same or similar content (Feldman, 1996). Although this reflective activity may take time and effort by science teachers (and their professional development facilitator), it empowers the teachers to control their own on-going development. Its rewards would be great in the long term.

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