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Understanding a High School Physics Teacher's Pedagogical Content Knowledge of Argumentation

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Abstract Scientific argumentation is an important learning objective in science education. It is also an effective instructional approach to constructivist science learning. The implementation of argumentation in school settings requires science teachers, who are pivotal agents of transforming classroom practices, to develop sophisticated knowledge of argumentation. However, there is a lack of understanding about science teachers' knowledge of argumentation, especially the dialogic meaning of argumentation. In this case study, we closely examine a high school physics teacher's argumentation-related pedagogic content knowledge (PCK) in the context of dialogic argumentation. We synthesize the teacher's performed PCK from his argumentation practices and narrated PCK from his reflection on the argumentation practices, from which we summarize his PCK of argumentation from the perspectives of orientation, instructional strategies, students, curriculum, and assessment. Finally, we describe the teacher's perception and adaption of argumentation in his class. We also identity the barriers to argumentation implementation in this particular case and suggest solutions to overcome these barriers.

Keywords Argumentation · Pedagogic content knowledge (PCK) · Constructivist science learning

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Introduction

Argumentation is a pivotal activity inherent in the process of scientific exploration (Osborne, Erduran, & Simon, 2004). In science education, argumentation represents the ability of selecting the optimum solution from its alternates in light of evidence normally to an ill-structured, controversial, and debatable problem (Sadler, 2006). It is an important learning objective required by national standards throughout all grade levels (NRC, 2013). On the other hand, argumentation is an effective approach to inquiry teaching in terms of exposing students to not only content knowledge but also to raw data where knowledge is derived as well as to the process of knowledge construction (Riegler, 2001). Engaging in argumentation can deepen students' conceptual understanding because when students try to persuade others, they engage in the organization of their thinking, as well as the comparison and reconciliation of different plausible accounts (Sadler & Zeidler, 2005). Correspondingly, argumentation is prevalent component in the literature regarding science education reforms.

Science teachers play a key role in integrating argumentation into science classrooms (McNeill & Knight, 2013). Unfortunately, science teachers, both pre-service and in-service, possess insufficient knowledge about argumentation (Zohar, 2007). Thus far teacher education regarding argumentation has been designed mainly to present teachers with innovative argumentation activities and appropriate instructional strategies with the assumption that teachers would automatically copy these activities in their teaching. Attention has been casted to teachers' knowledge of the structural meaning of argumentation (Berland & Reiser, 2009). Little work has been done regarding teachers' knowledge of the dialogic meaning of argumentation (McNeill & Knight, 2013; Zohar, 2007). In this study, we give a broader insight into a science teacher's pedagogical content knowledge (PCK) of argumentation with Magnusson, Krajcik, and Borko's model (1999) from both performed and narrated perspectives. We try to answer the question of what was the physics teacher's PCK of argumentation, which is guided by the following two subquestions:

1. How did the teacher interact with this students differently after engaging in dialogic argumentation?
2. How did the teacher describe his PCK regarding dialogic argumentation?

Theoretical Framework

Scientific argumentation is a process of forming reasoning and drawing conclusions in an attempt to persuade the potential audience to accept a certain position or a point of view (Simon, Erduran, & Osborne, 2006). Jiménez-Aleixandre and Erduran (2007) claimed dual meanings of argumentation from both individual and social perspectives. From the individual perspective, argumentation refers to a reasoning process regarding the construction of a conclusion. From the social perspective, argumentation refers to an interactive process in managing disagreement between people with different, normally opposite, opinions. The two perspectives are also known as the structural and dialogic meanings of argumentation (McNeill & Knight, 2013). Research regarding argumentation has mainly focused on the individual/structural meaning of argumentation by treating it as a learning outcome or a skill that students need to possess. Attention has been casted to the input and output of an educational intervention in promoting individuals' argumentation skill and understanding. Despite the findings of effective argumentation practices, argumentation rarely happens in science classrooms (Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). One of the reasons is that science teachers may not adopt argumentation interventions as educators have expected. It is necessary to understand how teachers perceive argumentation and adapt it to their classroom context through investigating the interactive process, i.e., the social/dialogic meaning, of argumentation (Berland & Reiser, 2009).

PCK is an appropriate tool to structure and connect multiple aspects of science teacher's knowledge of argumentation. Shulman (1986) defined PCK as distinctive knowledge that distinguishes teachers from content specialists. PCK describes a teacher's capacity to "transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by students" (Shulman, 1987, p. 15). Shulman claimed that strong PCK is the difference between experienced and novice teachers. The development of PCK requires teachers to develop understandings of content knowledge, their students, and the approach to transforming content knowledge into forms that students can easily grasp. Magnusson et al. (1999) suggested a framework of PCK that contains five components, including orientation, knowledge of curriculum, knowledge of instructional strategies, knowledge of students, and knowledge of assessment.

In this study, we adopted argumentation interventions from previous studies to create an argumentation-oriented environment in a high school physics classroom. During the process of argumentation, we recorded the physics teacher's interactions with his students and his reflection on the argumentation activities. Based on his behaviors and narrations, we mapped out the physics teacher's PCK of argumentation.

Literature Review

Scientific Argumentation

Argumentation has been widely accepted as a reformed instructional approach to transforming traditional science classrooms (Osborne et al., 2004). Thus far, studies regarding argumentation have been conducted mainly on the structural meaning of argumentation, especially the quality of an argument. Toulmin's (1958) argumentation pattern (TAP) is the cornerstone framework for argumentation analysis. TAP suggested claim, data, backing, warrant, and rebuttal as the pivotal constructs for argumentation. In later studies, TAP has been simplified into four components of claim, evidence, justification, and rebuttal (Osborne et al., 2004; Sadler & Donnelly, 2006). The four-component framework serves to guide the assessment of argumentation and the design of argumentation-based pedagogies, such as citing students' everyday experiences as evidence (Jiménez-Aleixandre & Puig, 2012), organizing chunks of evidence to scaffold students' justification (Sandoval, 2003), and embedding argumentation in social-scientific dilemmas to prompt rebuttals (Zohar & Nemet, 2002). In this study, we design argumentation innovations in reference to the studies regarding the structural meaning of argumentation, which we will discuss later in the research design.

In comparison, few studies in the argumentation strand have investigated the dialogic meaning of argumentation (Duschl, 2007). Researchers mainly treat argumentation as a learning product in terms of students' engagement in argumentation and the quality of their arguments (Nielsen, 2013). In actuality, argumentation is a socially interactive activity in the first place (Osborne et al., 2004). Researchers of the structural argumentation strand inevitably have to attend to dialogic argumentation, but they normally choose to circumvent problems or make implicit efforts on them (Nielsen, 2013). Among the limited studies that explicitly address dialogic argumentation, there is a mismatch between the intended focus of study and the research design. For instance, Kim and Song (2005) claimed that they focused on "the process of argumentation rather than the form and content of the argument" (p. 215). Eventually, they concluded about the types of argumentation strategies that students would use in different stages of argumentation. Naylor, Keogh, and Downing (2007) also claimed that they shifted their focus "from the logical content or linguistic elements of the argument and to focus instead on the process of argumentation" (p. 36). However, the downing model that they applied was measuring the students' performances in argumentation. In other words, these two studies consider the sequence of argumentation in communication, but the information about the arguers and the argumentation context is absent.

Besides an activity, argumentation in the science community also denotes a culture of evidence-oriented negotiation for knowledge construction (Osborne et al., 2004). Unfortunately, there is a lack of understanding about the accommodation for the culture of argumentation offered by science classrooms. Insufficient attention has been paid to the context of science classrooms and how that factor may affect the adaption of argumentation by a science class. In this study, we investigate a physics teacher's argumentation-related PCK in the context of dialogic argumentation with the intention of understanding argumentation from a science teacher's perspective. We focus on the interactive process of argumentation rather than the quality of individuals' arguments.

Teachers in Argumentation

Science teachers are key to argumentation implementation because they are pivotal agents of transforming classroom practices (Sampson & Blanchard, 2012). Thus far teacher education regarding argumentation has been designed mainly to present teachers with innovative argumentation activities and appropriate instructional strategies. For instance, Ozdem, Ertepinar, Cakiroglu, and Erduran (2013) found that high-quality argumentation occurred most during critical discussions after an experiment. They suggested that an inquiry-oriented investigation environment provides discourse opportunities that support argumentation. McNeill and Pimentel (2010) claimed that argumentative discourse is related to the teacher's questioning strategy. According to this study, student-and-student discussion and students' active response to their peers' ideas happened in a class where the teacher used open-ended questions and explicitly connected students' opinions to previous students' comments.

Those efforts have built a repertoire of successful argumentation activities for science teachers. However, they have limited influence in transforming science teachers' instructional practices (Osborne et al., 2013). For instance, McNeill and Pimentel (2010) at the end of their study pointed out that despite the achievement they have made, the norms of argumentation regarding justifying and connecting ideas were still absent in the science classrooms. One of the reasons is that teachers' professional development is a long-term and nonlinear process (Zohar, 2007). Osborne et al. (2013) claimed that it took 2 years for the teachers to become familiar with the goals and the appropriate instructional practices of an innovative curriculum. Besides the long time span, teachers' professional development also requires massive resources. The professional development for argumentation requires "more resource of teacher time, peer support, or coaching and models of what are the major identifiable steps in pedagogic practice with argumentation in school science" (Osborne et al., 2013, p. 341). Therefore, transforming teachers' practices requires sustained efforts.

Another reason is that little research has investigated science teachers' understanding of argumentation (McNeill & Knight, 2013). Zohar (2007) pointed out that teachers' stubborn beliefs about science teaching are a barrier to argumentation practices. Science teaching in traditional settings is characterized as being teacher-centered and factual knowledge-oriented (Simon et al., 2006). Sadler (2006) found that the more teaching experience a teacher has or the higher degree of education that a teacher receives, the more likely that she/he would ignore provided information but use her/his existing knowledge to solve a problem. Consequently, experienced teachers tend to prioritize authority in their instruction. However, argumentation requires an emphasis on evidence and reasoning, as well as valuing alternative perspectives and attending each other's opinions (Osborne et al., 2004). Therefore, the practice of argumentation can pose a considerable challenge to many science teachers' pedagogic knowledge. We cannot expect argumentation to happen in classrooms unless science teachers have developed sophisticated understanding of it. The model of PCK is an advantageous tool to map out a teacher's knowledge about teaching specific content (Shulman, 1986). In this study, we apply the framework of PCK to understand a physics teacher's knowledge of argumentation.

Teachers' PCK of Argumentation

It is a complex task to examine teachers' PCK because this body of knowledge is usually tacit (Loughran, Mulhall, & Berry, 2004). Sometimes even experienced teachers cannot articulate their PCK behind their teaching practices. From researchers' viewpoint, a teacher's PCK may not be evident within a short period of time. In response to those difficulties, Loughran et al. (2004) suggested the approach of content representation (CoRe) and pedagogical and professional experience repertoires (PaP-eRs) to uncovering teachers' PCK. This approach involves an iterative process of observing teaching practices, reflecting on particular teaching episodes, and sharing ideas of teaching a range of science topics. The idea behind this approach is that teachers' PCK needs to be captured from both narration and practice in contextualized situations. In this study, we borrow this idea by examining both narrated and performed PCK of the participating teacher.

Research regarding teachers' PCK of argumentation has focused on the difficulties in argumentation implementation reported by science teachers. Sadler (2006) identified three common barriers that a majority of teachers have brought up: students low ability level, limited time in class, and teachers' lack of knowledge about how to engage students in argumentation. McNeill and Knight (2013) designed a professional development program to gauge science teachers' PCK from two perspectives: knowledge of students' conceptions and knowledge of instructional strategies. They identified the struggles of science teachers in analyzing both structural and dialogic characteristics of argumentation, applying reasoning to classroom practice, and designing argumentation questions. Those studies have shed light on one or two components of PCK, such as teachers' knowledge of students in argumentation, but missed other critical components of PCK which also shape teachers' instructional practices. In this study, we are trying to depict an integral structure of science teachers' PCK from the five components of PCK suggested by Magnusson et al.'s model (1999), in the effort to give a broader insight into a science teacher's knowledge of argumentation.

Method

Case study is a research approach typically including multiple sources of data to provide an in-depth description of an entity under study. A case study focuses on "understanding why the individual does what he or she does and how behaviors change as the individual responds to the environment" (Ary, Jacobs, Razavieh, & Sorensen, 2010, p. 455). Therefore, case study is an advantageous method for us to investigate a particular teacher's interaction with his students as his response to argumentation innovations. We are aware of the disadvantage of case study that it potentially yields to subjectivity or even prejudice. The preconceptions of investigators can determine which behaviors to observe and how the observations might be interpreted (Ary et al., 2010). In this study, we were not trying to generalize our findings but honestly describing a physics teacher's PCK. Conclusions were made when the performed and narrated data converged. This strategy greatly helped reducing our bias.

Research Context and Participants

This case study took place in a public high school located in a town with a population of 80,405. This high school had an enrollment of 1517 students from more than 28 countries. It operated on a block schedule with students taking four 85-min courses on some days and four 85-min courses on the alternating days. At the time of the study, there were totally two physics teachers in this school. Mr. Ferris is a white male. He had over 40-year experience teaching physics. Mr. Ferris has a master's degree in physics, and he was teaching physics of all levels, including college preparation (CP), advanced placement (AP), and Honors physics. Mr. Ferris was in charge of designing physics curricula for both teachers. According to our pilot observation from February to May in 2013, Mr. Ferris was a traditional physics teacher who relied primarily on didactic instruction.

The other teacher, Mr. Jack, was the cooperating teacher. Mr. Jack is a white male. He had 25-year experience teaching physics, chemistry, and biology. Mr. Jack has a master's degree in biology. He was teaching AP biology, CP chemistry, and CP physics. Based on our pilot observation, Mr. Jack was a teacher with a balanced orientation that stayed in the middle of the inquiry continuum. He claimed for student-centered learning, so he often interacted with students during class and solicited students' ideas before revealing the answer. On the other hand, his arrangement of class followed the traditional didactic model, in which key content was instructed first, followed by an experiment verifying that knowledge. Mr. Jack primarily used lecture for instruction. In Mr. Jack's words, he has realized the problem of the format of didactic teaching. In his AP biology class, he had tried to inspire students to think and talk through asking open-ended questions or designing inquiry laboratories. However, according to Mr. Jack, he had never applied those strategies in his physics class because his physics instruction was largely guided and shaped by that of Mr. Ferris. Furthermore, Mr. Jack held a belief that physics knowledge is abstract and set in stone, which leaves limited space for inquiry teaching.

This study was carried out in Mr. Jack's CP physics class where there were 23 students, 14 males and 9 females. Eighteen of the 23 students were 11th graders. The others were two 10th graders and three 12th graders. The ethnographic composition was 20 whites, 1 Asian, and 2 African-Americans. The students took this class in the third block (1:30–2:50 pm) on Tuesday and Thursday for 1 week and Monday, Wednesday, and Friday for the alternating week. The physics content knowledge involved was classic mechanics for the fall 2013 semester and thermodynamics for the first half of the spring 2014 semester. The students had a practice class beforehand in which they could work on problems identical to those in the summative test.

Research Design

The goal of this study is to understand Mr. Jack's PCK of dialogic argumentation. We gauged Mr. Jack's performed PCK through comparing his interaction with his students before and after the implementation of the argumentation innovations introduced below. We gauged Mr. Jack's narrated PCK through collaboratively designing and reflecting on the argumentation practices. This study lasted from October 2013 to March 2014. In the first month, we observed the classroom dynamic under its natural state. From November 2013, we started to implement argumentation innovations in order to prompt arguments in class. Previous literature has suggested that activities designed for argumentation should be flexible or complex enough to allow for multiple opinions and alternative explanations, which would lead to a balanced interaction such as a debate (Jiménez-Aleixandre & Erduran, 2007). For instance, Zohar and Nemet (2002) contextualized argumentation in the dilemma of human genetics which does not have one simply correct answer. Meanwhile, educators also suggest that argumentation activities should prioritize evidence rather than authority as the support for a claim (Simon et al., 2006). Relying exclusively on authority would lead to confirmation bias in one's reasoning that people only see positive evidence that aligns with authority but overlook negative one (Norris, Philips, & Osborne, 2007). McNeill and Pimentel (2010) suggest that teachers take a partner role working side by side with students rather than a mentor role as the content authority during argumentation. Based on the ideas of previous studies, we incorporated three argumentation innovations: inquiry laboratories, conceptual questions, and open-ended discussion projects.

In the inquiry laboratories, verification experiments were replaced with explorative ones. Each experiment was led by an overarching question. The students needed to collect evidence to answer that question and to build the corresponding knowledge. Mr. Jack prepared the students with background knowledge and the acquaintance with laboratory equipment. Discussion of the overarching question and related content knowledge happened after the students fully investigating a topic. Conceptual questions served for the students to apply the content knowledge they had learned in real-life scenarios. Some exemplary contexts were the weight in a moving elevator regarding Newton's laws and floating in the Dead Sea regarding buoyancy force. The conceptual questions were used at the end of a chapter, and they required textual answers, which were more complex than plug-and-chug calculation questions. There were two open-ended discussion projects. One was about the mechanism of a sail boat and the other was about designing and applying perpetual motion machines. The two projects involved multiple topics, so it is difficult to boil the problem down to one simple physics model. The students had the freedom to cite evidence from a variety of sources. They needed to synthesize provided information, locate related content knowledge, and then draw conclusions. It is necessary to emphasize that we applied those argumentation innovations not to test their efficacy but to create an argumentative environment. Research has found positive evidence for those interventions, so we expected to prompt more arguments from the teacher and students with them. However, we did not expect the teacher to adopt those interventions exactly as we had expected. We wanted to see how the teacher might accept or adapt those interventions and then to gauge his performed PCK of argumentation.

Data Collection and Analysis

We collected the data of Mr. Jack's PCK from the circle of co-designing a class, observing the class, and reflecting on the class. The primary data sources were classroom observations, reflective debriefings, and teacher interviews.

Classroom Observations

We observed all Mr. Jack's physics classes throughout the entire study. Two video cameras were set up in the classroom. One camera was operated in the front to capture the details of special events and the other was set at the back to capture the entire class. An audio recorder was placed near 2–3 selected students who agreed to participate in this study. We paid close attention to them for 2 weeks, and then shifted to another 2–3 students with different backgrounds in terms of test achievement and argumentation skills. The audios were used to provide supplementary data about teacher–student argumentation. The focus of this study is on Mr. Jack's PCK, so we do not present students' background data in this paper. After each observation, we transcribed the audio and video records. Then we synthesized all the data into one document within which we identified and analyzed argumentative discourses. In this study, we defined an argument as a spontaneous statement with a clear position in the attempt to contribute to a discussion.

Within each vignette of argumentation, we analyzed Mr. Jack's performed PCK via observing foreground information (words, actions, facial expressions etc.) and inferring background information (intentions, perceptions, feelings, etc.). Magnusson's model defined the five components of PCK (Table 1). Accordingly, we coded any of the five components of Mr. Jack's PCK appearing in the foreground information. For instance, the topics or facilitating materials that Mr. Jack used in class were coded as curriculum (C). The procedure of Mr. Jack conducting an argumentation activity or the way he responded to a student's challenge was coded as instructional strategy (I). Afterward, we analyzed the background information by interpreting our observations and then coded any of the PCK components. For instance, if we observed that Mr. Jack quickly spoke for a student while the student encountered a difficulty while discussing something with the class, we interpreted Mr. Jack's behavior as not trusting that the students, both the speaker and interlocutors, could accomplish a certain task. Then we coded our interpretation as student (S). After coding, we constructed a scratch of Mr. Jack's performed PCK of argumentation, then refined it by reflective debriefings and compared it with Mr. Jack's narrated PCK.

Reflective Debriefings

In order to verify our analysis of Mr. Jack's performed PCK, we invited him to watch 5–6 selected short video clips once every 2 weeks to reflect on the intentions behind his speech acts and to interpret the speech acts of his students in a particular argumentation vignette. We also invited students involved in teacher–student

Table 1 Codes of PCK components (Magnusson et al., 1999)

Argumentation-related PCK	Codes	Definition
Orientation	O	Knowledge of the role of argumentation in science education
Instructional strategy	I	Knowledge of the appropriate instructional strategies to perform argumentation
Students	S	Knowledge of the students' background that would affect the argumentation practices in class
Curriculum	C	Knowledge of the implementation/adaption of argumentation in the existing curriculum
Assessment	A	Knowledge of the approach to assessing students' performances in argumentation and the efficacy of argumentation practice in facilitating students' learning

argumentation to reflective debriefing with the absence of Mr. Jack. Some exemplary questions we asked were:

> How did you feel/think when s/he did/said…?
> Why did you do/say that…? How do you think s/he might feel about it?
> What were the thoughts going through your mind at that moment?
> What did you mean by saying/doing?
> What does this response from the student indicate about his understanding of…?

All the reflective debriefings with both Mr. Jack and his students were audio-recorded, which serves as supplementary data to better understand the dialogic argumentation in class.

Teacher Interviews

The interviews with Mr. Jack happened on a weekly basis during class preparation and reflection. We asked questions indirectly gauging Mr. Jack's PCK. Some exemplary questions were:

> When do you think is appropriate to have the class discussion about the conceptual questions? Before or after your instruction?
> How do you want to carry out the group discussion on the argumentation questions?
> We have prepared some candidate argumentative questions for this chapter? Which one would you like to use?
> What difficulties do you think that the students may have in this experiment?
> What can you tell from the students' answers to this question about their understanding of this concept?

The interviews with Mr. Jack were audio-recorded as well. We transcribed the audio records and coded Mr. Jack's narrated PCK in the same way as we did with his performed PCK (Table 1). We analyzed Mr. Jack's performed PCK via class observations and reflective debriefings, and his narrated PCK via interviews. Then, we identified the commonality between the two sets of data, based on which we mapped out Mr. Jack's PCK of argumentation. Conclusions were made based upon agreement between us. The validity of the findings is strengthened by structural collaboration that we collected large quantities of data from multiple sources which relate to each other to support a claim, and interpretive adequacy that we verified our analysis with the research subject through the process of reflective debriefing (Ary et al., 2010).

Findings

In this section, we present the findings for both sub-questions. First, we compare the interaction between Mr. Jack and the students before and after implementing argumentation innovations. By doing so, we are not tracing the change of Mr. Jack's PCK because it is stable (Shulman, 1986). We use the teacher–student (T–S) interaction in normal classroom settings as a reference to the interaction in dialogic argumentation in the effort to understand Mr. Jack's PCK of argumentation evolved as a response to argumentation practices. Second, we present the data of Mr. Jack's narrated PCK.

Q1: T–S Interaction from Normal to Argumentation-Leveraged Class

In Normal Classroom Settings

Mr. Jack used lecture as the primary instructional approach. The quote below is an example of Mr. Jack's lecturing. Before demonstrating an experiment of projectile motion, Mr. Jack polled the students on which one would hit the ground first, a ball shot out horizontally by a cannon, a ball falling down freely, or at the same time. There were supporters of all three answers. After the poll, Mr. Jack gave the answer directly.

Mr. Jack: Why it's the same? Gravity, because gravity is only working downwards, what if there is no gravity? One will stay in the air, the other will go straight forward, because no force is pulling it down.

Mr. Jack gauged the students' preconceptions about projectile motion, but his probing effort seemed to stay at a factual level. In other words, Mr. Jack seemed to care about what the students' answers were and whether their answers were correct, but not how they came up with the answers. It was a good opportunity for argumentation when the students reached a disagreement. Before launching the explanation, Mr. Jack could have called up one representative from each answer to elaborate on their reasoning. Instead, Mr. Jack accomplished the reasoning by himself. He answered his own question. In this vignette, Mr. Jack appeared to be a lecturer responsible for presenting students with the correct and complete information. Correspondingly, the students appeared to be receivers who followed the lead of their teacher. Mr. Jack lectured probably because the concept of projectile motion was new to the students. After the students accessed projectile motion, Mr. Jack still dominated the conversation with the students. As shown in the quote below, Mr. Jack had already introduced the formulas of projectile motion and demonstrated the application of the formulas in calculus problems. Then Mr. Jack was summarizing the procedure of solving projectile motion questions in a step-by-step manner. Similarly, Mr. Jack answered his own questions and left none for the students to answer.

1 Mr. Jack: What should we do next? Solve the triangle. Sin and Cos, Sin of theta, opposite
2 over hypotenuse, Cos of theta, adjacent over hypotenuse, what's opposite? F parallel.
3 What's adjacent? F perpendicular. There you go, that's all your equations…

Another feature of T–S interaction was math-oriented. In normal classroom settings, Mr. Jack presented physics knowledge primarily in the form of formulas and equations. Conceptual understanding was less emphasized than calculating. The quote below is an example of Mr. Jack addressing the procedure of solving a calculus problem.

1 Mr. Jack: Do we know the acceleration?
2 Students together: Yes.
3 Mr. Jack: How about the time?
4 Paige: That's what we are trying to find out
5 Mr. Jack [to the class]: Do you remember the formula?
6 Paige: No
7 Mr. Jack: Here it is, just plug in, [plugging in the numbers and did the calculation], now
8 we get the answer. Are we done?
9 Paige: No, Multiply it by 2

Mr. Jack simplified projectile motion into a two-dimensional physics model, and equalized problem solving to plug-and-chug. Mr. Jack modeled a standard procedure for problem solving in an order of listing related equations (Line 5), identifying knowns and unknowns (Lines 1 and 3), plugging in numbers (Line 7), and finally calculating (Lines 8 and 9). Correspondingly, Mr. Jack seemed to assess the students' understanding through gauging whether they remembered the procedure instead of how well they understood projectile motion. For instance, there was no evidence of the students thinking about why a projectile motion needs to be separated into horizontal and vertical motions. Again, Mr. Jack appeared to be a lecturer responsible for simplifying physics learning into a memorable procedure. Not surprisingly, the students appeared to be receivers who learned physics concepts by rote and reinforced their memories through repeated practices.

The third feature of T–S interaction was that Mr. Jack's conversation with the students followed the IRE pattern that he *initiated* a question, the students *responded* to that question, and he *evaluated* the students' responses. In the vignette below, Mr. Jack was working with students on a problem about figuring out muzzle velocity.

1 Mr. Jack: How are you gonna do that?
2 [Paige, Charlie and Tina guessed with the answers of "angle", "use formulas", and
3 "measure something"]
4 Mr. Jack: Think about the projectile, think about these equations [pointing to the
5 equations on the board] … OK, say some very, very important things. One was?
6 Paige: Distance and time.
7 Mr. Jack: Distance and time… [looking to Mike] You said something else with distance,
8 which is important.
9 Paige: [answering before Mike] How far is it vertically.
10 Mr. Jack: [pointing at Paige] Bingo

Mr. Jack expected the students to recall the procedure of solving muzzle velocity, i.e., using the vertical distance to determine the time (Lines 7–9) and then solving the muzzle velocity with the time and the horizontal distance (Lines 4–6). Thus, he seemed to already expect the key words before asking the question, which were vertical distance and time. The students answered Mr. Jack's questions by guessing with key words without elaborating on them (Lines 2, 3, 6 and 9). It looks like that Mr. Jack accepted the students' answers and assumed that the students understood a concept if they could nail the key words (Line 10). Actually, most of the students' answers were vague. For instance, the students did not elaborate on how to "use formulas", "measure" what, or how "distance and time" apply to this scenario. Some spokespersons, who was Paige in the vignette above, answered Mr. Jack's questions on behalf of the entire class. Paige randomly threw out three guesses (Lines 2, 6, and 9) and answered before Mike (Line 9). Finally, she nailed the right answer, but there is no evidence suggesting that she understood how vertical distance fit into the picture. In another example, Mr. Jack was asking the students which one, between a falling piece of paper and a falling elephant, experiences a greater air resistance force. The students shouted out both answers.

1 Charlie: It's the elephant, because it has more mass, more force.
2 Mr. Jack: OK, keep partial on that, partial. Yes, the elephant does have greater air
3 resistance, but is that because of its mass?
4 Harry: Surface area?
5 Mr. Jack: Right, surface area. Definitely elephant. The piece of paper itself does not have

6 a whole lot of mass, that's right. But the surface area, the elephant has more air pushing
7 up on it.

Similarly, Mr. Jack seemed to already have expected answers for his question, which were "elephant" as the right answer (Line 2) and "surface area" as the correct justification (Line 5). Mr. Jack probably positioned himself as the lecturer who assessed the students' responses by the presence of the right terms. Therefore, Mr. Jack told Charlie to keep partial on his answer (Line 2) because only the "elephant" part in Charlie's answer matched Mr. Jack's expectation. Interestingly, during the reflective debriefing, Charlie commented that:

> Charlie: "I thought that the terminal velocity is when the force down [weight] equals the force up [air resistance]. An elephant is much heavier than a paper, so it requires more air resistance to achieve, what the term, equilibrium… Mr. Jack said it is the surface area, so be it. He must be right."

Charlie's justification is reasonable and he viewed this problem from the perspective of equilibrium status. Unfortunately, Charlie did not have chances to share his idea with the class. At the moment when Mr. Jack commented on Charlie's answer (Lines 2–3), Charlie seemed to quickly ditch his valuable thought and yielded to the authority of Mr. Jack. Again, this discussion ended with Mr. Jack's lecturing.

In Argumentation-Leveraged Settings

Differences in T–S Interaction After bringing in argumentation innovations, Mr. Jack exposed his students to their peers' opinions before he gave instruction. In the vignette below, Mr. Jack was asking the students which one has a larger pressure, between 1 m in an ocean and 1 m in a diving well. The students shouted out different answers.

1 Mr. Jack: Whoa, I hear both. OK, let's stop here for a moment. Discuss within your
2 group. Group of four, talk real quick, come on, talk, talk, talk. (O)
3 [After group discussion, each group selected a representative to share their group
4 answer. Students' group answers varied]
5 Mr. Jack: Interesting separation. OK, let me ask you this, is that [gravity acceleration, g]
6 the same?
7 [Students nodded and said yes.]
8 Mr. Jack: OK, gravity is gravity, it's the same, in the ocean or the diving well. [Pointing
9 at h]So does this change whether you are in the ocean or the diving well?
10 [Students waved their heads.]

11 Mr. Jack: No, that's the same. These guys are the same, so what's the only guy left?
12 Density. So what is more dense, the water here in the diving well or the ocean? (O, I)

The T–S interaction was more student-centered. First, Mr. Jack left time for the students to discuss in small groups before revealing the answer (Lines 1–2), which suggests that Mr. Jack probably perceived argumentation as an approach to exposing students to each other's ideas. After noticing the students' various answers, Mr. Jack broke apart the question and guided the students to notice that the key to the problem is density (Lines 5–6, 8–9, and 11–12). He applied the scaffolding strategy of guiding the students through the reasoning chain. In this vignette, Mr. Jack seemed to be more patient and pay more attention to the students' thoughts. A more student-centered interaction between Mr. Jack and the students is also epitomized by Mr. Jack explicating the students' ideas to the class. The vignette below is about a conceptual question regarding using buoyancy to measure the weight of a car with given materials. The students worked in groups on the plan first and then Mr. Jack led a class discussion.

1 Mr. Jack: OK, I think a lot of you guys have some great ideas, and I want to bring them
2 out. Um, I have two groups so far that I have identified two ways that I wasn't even
3 thinking about. Besides yours [Kevin's group] and besides you guys [Barbara's group].
4 OK, what are some other ideas? (I)
5 Other groups shared their ideas.
6 Mr. Jack: Now, these guys [Barbara's group] have an interesting one. Unfortunately,
7 they couldn't solve it using the knowledge they currently have. By the end of the chapter,
8 they should be able to. Can you guys do as much as you can? And I will fill in if I need to.
9 (I)

As shown in the excerpt above, Mr. Jack used two strategies to bring the students' attention to their peers' ideas. First, he acknowledged the value of the students' own ideas (Lines 1 and 6). He appeared to be the guider who controlled the pace of the discussion, and the sequence of information that the students accessed in the order from orthodox and easy ideas to unconventional and complex ones (Lines 2–3). Through this approach, the students probably were more willing to pay attention to alternative ideas once their own were addressed. Second, Mr. Jack encouraged Barbara's group to present their idea by themselves (Line 8). It looks like that he served as the facilitator for the students' presentation. In addition to being student-centered, Mr. Jack's instruction emphasized conceptual understanding more. In the quote below, Mr. Jack was giving pre-laboratory instruction on momentum.

1 Mr. Jack: What's momentum?
2 Jared: Something moves, and what keeps pushing it.
3 Mr. Jack: Oh, yes, there is a little bit, and? (I)
4 Jared: When something moves, it's [momentum] something pushing it by, when, like a
5 ball rolls down a hill, and make it to the other hill, the momentum kind of pushes it up the
6 other hill
7 Mr. Jack: OK, that's some relationship with it, sure… now, I know, Norris do you want to
8 say something? (I)
9 Norris: So it's kind of the velocity times something.
10 Mr. Jack: Yes, that's true. But what does that mean? I mean you are right, we can all see
11 m times v, that's what momentum means, but we need to understand momentum itself (A)

Instead of walking the students through the laboratory procedure directly, Mr. Jack was preparing the students with the necessary background knowledge about momentum before the lab, i.e., what is momentum (Line 1). Mr. Jack probably tried to lead the students' attention away from the mathematic representation of momentum to the physics concept behind it. When Jared described momentum with a vague notion of "something moves an object", Mr. Jack encouraged Jared to elaborate on his answer (Line 3). Although Jared did not clearly define momentum, he described momentum correctly in his own words (Lines 4–6). Meanwhile, Mr. Jack called on Norris, who was a silent student, to share his opinion with the class (Line 7). As a result, more students rather than a couple of spokespersons participated in the class discussion. He also emphasized that momentum is beyond the mathematic formula of velocity times mass (Lines 10–11), which suggests that Mr. Jack probably perceived this argumentation innovation as an approach to deepening students' conceptual understanding.

Similarity in T–S Interaction Some features of the T–S interaction remained the same after the argumentation interventions. One was the IRE interaction pattern between Mr. Jack and students and the other one was the social hierarchy between Mr. Jack and the students. Argumentation-integrated curriculum requires evidence-based instruction in terms of presenting evidence and constructing reasoning to generate a conclusion (Osborne et al., 2004). The T–S interaction was authority-oriented both before and after the interventions. As illustrated in the previous section, Mr. Jack paid more attention to the ideas of a variety of students after the interventions. However, the class discussion still happened mainly between Mr. Jack and the students. The students seldom confronted with each other directly, but presented their ideas to Mr. Jack for evaluation. In the quote below, Mr. Jack was summarizing how to decompose a force vector with the parallelogram method in the sailboat project.

1 Paige: Can we make the parallelogram the way to the sailboat? [She went up to the
2 board and drew a different parallelogram]. How about making the parallelogram in this
3 way?
4 Mr. Jack: Sure, you can look at it in that way. It's a different way of doing it. Although
5 the only thing, I guess, [paused]. If we are looking at [paused]. That's a good idea, but I
6 think in particular if we just look at this as velocity, if we did it this way [Paige's way],
7 what happened to your vector [Paige's resultant vector]. Got bigger, right? So we are
8 just looking at the force the wind is pushing. (O)

Paige presented her different idea to Mr. Jack for verification (Lines 1–3). She did not challenge Mr. Jack's parallelogram even though the two approaches seemed to be incompatible with each other. Paige contributed to the class discussion with an alternative idea, but her parallelogram was incorrect. She might simply memorize the parallelogram method as decomposing a resultant vector into two components without understanding why to do so. Mr. Jack could have asked other students to comment on Paige's idea or explained to Paige why the resultant force should be perpendicular to the sail or what the two component vectors represented. Instead, Mr. Jack first acknowledged Paige's idea as being acceptable but a different way of decomposition (Line 4). Then he tried to convince Paige to accept the orthodox parallelogram by pointing out the error in Paige's parallelogram (Lines 5–7). At that moment, Mr. Jack was trying to guide Paige to realize the problem of her own thoughts. However, his justification seemed to be not convincing. His illustration that the resultant vector "got bigger" (Line 7) could not lead to any conclusions. Probably Mr. Jack was not prepared for Paige's question because he paused several times while answering that question (Line 5). Eventually, Mr. Jack quickly made a summary that "we are just looking at the force the wind is pushing" (Line 8), which indicated to the students that they should accept his parallelogram but not Paige's in that specific scenario. During the reflective debriefing, Mr. Jack stated that he did not want to leave the students confused so he had to give them a firm answer. This vignette suggests that Mr. Jack did pay attention to students' ideas. However, he still maintained his authority in terms of imparting the students assured knowledge rather than constructing knowledge together with the students with an equal social status. Paige commented during the reflective debriefing that,

> Paige: “I interpreted that [Mr. Jack’s explanation] as we were not trying to learn things actually applicable to real life, we were just learning basic things we need to know. It frustrates me.”

Paige seemed to interpret Mr. Jack’s response as that her parallelogram is correct but not applicable to that specific question because that question is a simplified physics model but not the real-life situation. Her response indicates that she probably did not see the application of the knowledge she learned in class in real lives. Paige seemed to perceive Mr. Jack’s parallelogram as “a basic thing” that she needed to memorize, and accepted it unconditionally due to Mr. Jack’s authority. In other words, Paige’s reasoning probably stopped at the moment when she received a firm answer from Mr. Jack. In another vignette, Mr. Jack was discussing resultant vectors with the students.

1 Mr. Jack: …OK, let me do this, I will call it R, the resultant. So what’s my R gonna look
2 like now? The same thing, right? [paused] Right? (I)
3 Students together: Uh-huh [in an agreeing tone]
4 Mr. Jack: Trying to mislead you, OK?
5 Students together: Oh.
6 Mr. Jack [Laughing]: I am kind of trying to mislead you here. So my R is not gonna be
7 the same as it was before when I first started. (O)

At first, Mr. Jack applied the strategy of prompting students’ argumentation with a wrong statement (Lines 1–2). He was probably expecting the students to attack the target that he set. However, the students seemed to perceive Mr. Jack’s words as instruction and mechanically accepted them (Line 3). Mr. Jack could have raised follow-up questions to help the students to locate the errors in his statement. Instead, he immediately gave up his prompting effort and shifted his role back to the authority (Lines 4 and 6–7). During the reflective debriefing, Mr. Jack admitted that he was afraid of confusing or misleading the students with incorrect information, so he had to make sure that his statements are always correct. Therefore, Mr. Jack’s instructional beliefs seemed to be inhospitable to uncertainty which lies in the core of argumentation. The quote below is another example of Mr. Jack maintaining the hierarchy in status with the students. Mr. Jack was leading a discussion about time dilation in relativity. Gary made a conjecture after Mr. Jack introducing the big bang theory and inferring that people could see the origin of the universe if they could reach the edge of the universe.

1 Gary: I know you just started this, but isn’t there like a parallel universe, like the same
2 thing exactly like this? Like [paused], technically, you may not be able to see in the
3 future, but see it in an alternate dimension, like, oh I see that

4 Mr. Jack: Well, that's a little different, I wouldn't say the future being existent, current
5 existence somewhere else, that's a whole other ball game, a whole other thing, kind of
6 hard. (S)

Gary's deduction is logically reasonable because there must be several parallel universes existing simultaneously if presence and past existed in the same universe. Mr. Jack could have expanded Gary' conjecture to a class discussion about the dimensions of the universe, or invited other students to comment on Gary' conjecture. However, Mr. Jack decided to terminate the discussion and categorized it as an issue beyond students' current knowledge (Lines 5–6). Mr. Jack described this topic as being "kind of hard", which suggests that he probably perceived the students as being incapable to discuss this particular complex topic of relativity. During the reflective debriefing, Mr. Jack stated that the objective for the relativity chapter was to help students learn some basic facts. Thus, he avoided going far in the discussion on relativity even though it was so open-ended that Mr. Jack could have explored the topic together with the students. Instead, he terminated the discussion even though Gary displayed interest towards this topic.

Q2: Mr. Jack's Narrated PCK of Argumentation

In this section, we use the quotation marks to directly cite Mr. Jack's words from the interviews.

Orientation to Argumentation

Mr. Jack stated that the objective for science education is "cognitive development". He expected the students to develop the skill of "recognizing what the problem is and knowing which solution to use for it". Scientific concepts are the vessel that carries such skills. In Mr. Jack's words, he "would prefer the more conceptual knowledge understanding of why things work with the supplementation of math". In practice, Mr. Jack tried to prioritize conceptual understanding. However, he had to follow the lead of the senior physics teacher, Mr. Ferris, who had been "the predominant only physics teacher since nearly 70s". Therefore, Mr. Jack's instruction was shaped by Mr. Ferris in terms of math-oriented physics teaching. Another reason is the pressure from state standards, as Mr. Jack stated:

> Mr. Jack: "There are so much in the state standards, you can't cover all anyway. Or you do, you only cover it so thin, you just introduce the material and you move on."

Mr. Jack also admitted that math-oriented instruction is "the easiest way" to fulfill the requirements of standards. Therefore, although he embraced the conceptual-emphasis feature of argumentation, he did not go deep in the argumentation about conceptual knowledge because it is "time consuming". In addition, Mr. Jack seemed to perceive argumentation as a practice of reinforcing the knowledge required by standards rather than expanding students' knowledge scheme through self-exploration. The evidence is that during the preparation for the open-ended discussion project of sail boats, we suggested to launch the exploration under an overarching question, such as "why is a sail designed in an angle with the wind?" and "what is the optimum angle between a sail and the wind so that the boat can move fastest?" Mr. Jack expressed his concern that this type of question is vague that would cause confusion or discursion in the students' discussion.

> Mr. Jack: "What I concern is, um, interjecting that [the sail boat activity] with vectors, I don't want to use the term of confusion. When we are done with the vectors, we will have a review. So this [the sail boat activity] could be part of a discussion in that review process."

The quote above suggests that Mr. Jack wanted to tie the sail boat project only to vectors. The mechanism of a sail boat is complex that involves many physics concepts. Mr. Jack decided to simplify the physics model by focusing exclusively on vectors but ignoring others, because vectors were required by standards. Mr. Jack was very careful about the accuracy of the information that the students accessed. According to Mr. Jack, science is "scarier to some kids" than other subjects. He felt obliged to make science easier for the students by providing them with what they need. In his words, a teacher "is supposed to have the knowledge that the students are trying to get". Thus, Mr. Jack perceived argumentation as one of the approaches to imparting the knowledge to students. He seemed not to welcome the feature of ambiguity or uncertainty in argumentation.

Instructional Strategies Regarding Argumentation

Mr. Jack made efforts in creating a comfortable environment for most of the students to share their ideas. He suggested argumentation in small groups before class discussion because "more of the students feel that they have to make contribution to the discussion versus in a classroom discussion, many students probably feel that I don't need to say anything." While grouping, Mr. Jack considered the composition of a group in order for members to have opportunities to voice themselves.

> Mr. Jack: "If there is a dominate person, I make sure there is a second dominator person, to balance it out. But if I have 3 quiet individuals, I don't put one dominator within them. I put 4 four quiet ones together, so they are gonna have to talk."

Mr. Jack was also aware of his role in group discussion. He admitted that he could "ruin a discussion by simply making one or two comments that shut off the discussion." On the other hand, he was afraid that some groups may "have done it in a minute". He claimed that a teacher needs to be a "devil's advocate" to prompt students' argumentation, and a teacher "cannot always be there" in a discussion in order to promote students' sense of agency in argumentation.

> Mr. Jack: "When I come to the table, they all turn their heads and look at me, and I like what are you looking at me for, I am not part of this, you talk, I am here just to see what you are saying, and maybe I want to throw something out, and sometimes, I would say something totally opposite, opposite simply to create dialogue."

We observed that class argumentation happened only between the teacher and students. While talking about this situation, Mr. Jack stated that his choice of instructional strategies was determined by the instructional goal.

> Mr. Jack: "It becomes cook-booking with the labs, because it's not sloppy … There are so much in the state standards… if some of this [inquiry teaching] has been messy, if you are feeling you are behind, you gotta get through these things."

The quote above indicates that Mr. Jack probably prioritized covering the content knowledge required by standards over inquiry practices as his instructional goal. Mr. Jack stated that the limited time in class was another reason why he chose the "most efficient" instructional strategies. Apparently, teacher-centered instruction is the optimum approach to easily and quickly transferring knowledge to students.

Students Involved in Argumentation

Generally, Mr. Jack seemed to perceive the students as being weak in learning abilities, which impeded them from participating in sophisticated inquiry activities, like argumentation. While talking about the students' laboratory skills, Mr. Jack commented that:

> Mr. Jack: "…say they put a 20 [a 20 grams weight] on, instead of taking the 20 off, putting a 10 [a 10 grams weight] on, they will go to the other side, add a 20. Then they will go, that's too far in that way, I am gonna add another 20 at this side, so keep going back and forth."

As shown in the quote above, Mr. Jack seemed to believe that the students were immature in laboratory skills for problem solving. Mr. Jack ascribed this problem to students' insufficient experiences with science learning. Biological limitation was another reason. Mr. Jack stated that "some students have not fully developed the frontal part of their brain yet", so it is beyond their physical ability to engage in higher-order thinking activities. Mr. Jack described another feature of the students as being indoctrinated.

> Mr. Jack: "…the kids, part of this is our indoctrination, just tell me what I need to do, and I will do it…you could not expect them to do much outside the classroom…Even if you do tell them that there is no black and white, they still think that there is one, and they want it."

As suggested by the quote above, Mr. Jack thought that the students did not possess appropriate epistemological beliefs for argumentation because they held a black–white dichotomous view towards science. In actuality, an accepted statement in science is not absolutely better than its alternatives. Meanwhile, he seemed to think that the students were lack of motivation in physics learning because he did not expect them to explore something on their own. The evidence presented above suggests that Mr. Jack perceived the students as passive learners who were incapable of independent learning, let alone constructing knowledge on their own. Thus, it is reasonable to assume that he did not think that all the students were ready for an inquiry task as complex as argumentation.

Curriculum for Argumentation

Mr. Jack expected that the argumentation curriculum used in class should be clear of ambiguity. In the quote below, Mr. Jack explicitly stressed his concern of the possibility of confusion caused by alternative explanations.

> Mr. Jack: "I am afraid if we start doing different ways, they are gonna just go, forget it [the orthodox way of solving a problem]."

Mr. Jack seemed to expect that the argumentation curriculum contain unambiguous information. In practice, Mr. Jack adapted most of the argumentation activities by reducing the amount of erroneous or heterodox explanations as the alternatives to the right answer. Another expectation of Mr. Jack on the argumentation curriculum was being stratified. Mr. Jack believed that not all students need to understand everything covered in the curriculum. In his words, the students just need to know "the most fundamental things". Practically, he expected that the students with various learning objectives and/or abilities need to receive different curricula or receive the same curriculum at different paces. Again, Mr. Jack probably did not perceive argumentation as one of the most fundamental objectives that all the students can/should master. He seemed to believe that argumentation is suitable to particular students, as he commented below

> Mr. Jack: "Argumentation is hard, I would say, a hard task for some of them [students]…I would say those who were more verbal students, more active, or more confident in physics, would benefit more [from the argumentation practices]."

Assessment Regarding Argumentation

Mr. Jack's knowledge of assessment has changed after his experiences with argumentation. Originally, Mr. Jack claimed that he was applying formative assessment, which referred to several quizzes that the students took before a formal test, as Mr. Jack described below

> Mr. Jack: "Every single one of their homework problems should be a formative quiz technically. The quizzes have questions exactly the same as those in a test… to see can they do a problem before we have a test next week…. They can take it as many times as they want. Say Paige, the one she was taking today was the third time taking that one. She wants to get an A."

As shown in the quote above, Mr. Jack seemed to perceive the function of formative assessment as to prepare the students for tests or to help them get a better grade. Mr. Jack acknowledged that his formative assessment was targeting the students' achievement because this approach was "easier, quicker, and less expensive." Mr. Jack also mentioned that he wished to apply formative assessment to differentiate the students into "who can and who cannot" as the first step for the stratified instruction. In other words, the formative assessment in his class yielded different labels tagged to different students. Thus, the claimed formative assessment was actually summative. After engaging in argumentation, Mr. Jack realized that argumentation could be used to assess the students' understandings from a different perspective. He commented that

> Mr. Jack: "The idea of conservation of energy. If you steal a little bit from this, you can't get something for nothing, because I mentioned that multiple times this year… It kinda surprised me when they [the students] didn't get it."
> Mr. Jack: "It's interesting, I don't understand… they [the students]worked on one of the problems… and it was an exactly same question, um, and it is surprising [that the students got the argumentation question wrong]"
> Mr. Jack: "Did they really make that connection that, as you going faster, it has to push harder because your velocity is going faster, so more centripetal force, I think a lot of them didn't make that connection."

The quotes above suggest that Mr. Jack has noticed that the students' achievement in standard tests cannot reliably represent their understanding of physics conceptual knowledge. He started to think beyond the correctness of the students' answer, but to what level the students understand a concept and how the students assimilate a new concept into their existing knowledge scheme. With argumentation, Mr. Jack seemed to start to assess the students from a formative perspective. Despite the efficacy of argumentation in assessing the students' conceptual understanding, Mr. Jack expressed his concern about the assessment of students' argumentation. First, Mr. Jack felt difficult to assess the efforts of reasoning that students put into argumentation. While talking about the amount of thoughts that students devote in argumentation, Mr. Jack stated that:

> Mr. Jack: "As a teacher, that's [students' efforts of thinking] much more difficult to assess. So how you assess, how do you distinguish between a group that has been lazy and just throw something together at the last minute versus another group that works really hard at it. That's difficult to do."

The quote above shows that Mr. Jack acknowledged the significance of the reasoning process behind argumentation, which to him was implicit and unmeasurable. Therefore, Mr. Jack found it hard to guarantee the fairness in argumentation assessment. Second, Mr. Jack was concerned of the lack of a formal rubric for argumentation assessment. In this study, the structural meaning of argumentation was assessed but this assessment did not contribute to the students' final grades. Mr. Jack emphasized that the students "would not take it (an argumentation task) seriously unless you push them hard to do it." While talking about the influences of standards on his instruction, Mr. Jack stated that:

> Mr. Jack: "Is it more important that the kids can number crunch, that they can get through this much material? No, it's more important that they understand the core material and they have the ability to apply or put something into a new situation, and predict certain outcomes or outcome they expected might not to happen. The hard part is that we don't test that."

This quote strengthens our conclusion that Mr. Jack prioritized conceptual understanding over calculation in his orientation. Besides, it also suggests that Mr. Jack's instruction was probably determined by the approach through which the students were assessed. Although Mr. Jack acknowledged the importance of the skills pertaining to argumentation, he felt difficult to address the skills in his instruction because they were not formally assessed. To Mr. Jack, the implementation of argumentation requires a reliable and legitimate rubric for argumentation assessment that is explicitly addressed in state and/or national standards.

Summary: Mr. Jack's PCK of Argumentation

After comparing Mr. Jack's performed and narrated PCK, we summarized Mr. Jack's PCK of argumentation in Table 2. Mr. Jack accepted the significance of conceptual understanding in physics learning. He acknowledged that argumentation is an appropriate approach to addressing and assessing students' conceptual understanding, but not an investigative activity for students to construct their knowledge. Mr. Jack had a low estimate on the students' abilities and enthusiasm towards physics. Together with the pressure from standards and limited time in class, Mr. Jack chose directly transferring instructional strategies because they are quick, easy, and reliable. He maintained his status as the authority during argumentation to guarantee the accuracy of the information transferred to the students. The argumentation-leveraged curriculum that Mr. Jack applied was clear of ambiguity and concepts off the list of standards. Although Mr. Jack acknowledged the importance of reasoning behind argumentation, he felt unhandy to emphasize it in his instruction because of the lack of a widely accepted rubric for

Table 2 Mr. Jack's PCK of argumentation

PCK components	Description
Orientation	An instructional strategy in addressing, promoting, and assessing students' conceptual understanding of content knowledge
Instructional strategy	Explicating students' thoughts, encouraging group discussion, and emphasizing conceptual understanding in a teacher-centered manner
Students	Passive learners with unsophisticated learning skills
Curriculum	Conceptual knowledge oriented, tied to content knowledge required by standards, and clear of ambiguity
Assessment	An effective approach to formatively assessing students' conceptual understanding, difficult to assess argumentation because of the lack of a formal and reliable rubric

assessment. Therefore, Mr. Jack only applied argumentation as an alternative learning task more complex than mathematical manipulation in addressing the content knowledge required by standards.

Discussion

Mr. Jack's PCK of argumentation sheds light on the perception of argumentation by a high school science teacher who implements this educational innovation. Argumentation has been positioned as a critical learning objective and an inquiry activity for knowledge construction (NRC, 2013). From Mr. Jack's perspective, argumentation is simply an instructional tool. On one hand, argumentation is a tool with which Mr. Jack can gauge students' deep thoughts because it is more sophisticated than plug-and-chug. On the other hand, it is a tool with which Mr. Jack can engage students both physically and mentally in his instruction because it is more interesting than memorization. As a tool, argumentation is only for teachers, but not appropriate for students because it can potentially yield misconception and confusion. In addition, Mr. Jack did not perceive argumentation as a primary learning objective for all students to achieve because it places additional intellectual challenges beyond some students' abilities. To Mr. Jack, argumentation is a secondary learning objective that needs to yield to the mastery of fundamental knowledge. In other words, argumentation is only suitable to particular students who have mastered prerequisite skills or knowledge.

Mr. Jack's PCK also explained the mismatch between the dialogic process of argumentation that we observed in this study and the dialogic meaning of argumentation suggested by educators. Ideally, dialogic argumentation in science classes should happen both between teachers and students and among students (Berland & Reiser, 2009). The participants of argumentation need to share different opinions and confront with challengers directly (Osborne et al., 2013). In this study, Mr. Jack served as the information center in charge of sorting, evaluating students' thoughts, and passing on the valuable ones to each other. The dialogic argumentation between Mr. Jack and the students after receiving argumentation interventions still followed the IRE pattern with the students' responses refined in two ways: (1) more students rather than a couple of spokespersons participated; (2) students' responses contained facts and reasoning beyond simply big words. Furthermore, argumentation is driven by uncertainty that all candidate explanations be fully respected and equally considered (Osborne et al., 2013). The norm of argumentation is evidence-oriented (Osborne et al., 2004) that the strongest candidate argument is the optimum answer. In this study, Mr. Jack set up the norm of dialogic argumentation as authority-oriented in terms of pursuing and accepting unique orthodox knowledge. Such a mismatch stems from Mr. Jack' knowledge of the students as being incapable, his knowledge of the argumentation curriculum as being set in stone, and his knowledge of the instructional strategies as being straightforward and quick.

In this sense, we did not significantly transform Mr. Jack's instructional practices with the argumentation innovations. It is reasonable because teachers' professional development is a long-term and non-linear process. In this study, we have encountered the several barriers to argumentation implementation identified by previous studies, such as teachers' unsophisticated knowledge of argumentation, teachers' low estimate of students' abilities, and limited time in class (Sadler, 2006; Sampson & Blanchard, 2012). We also identify two more barriers. One is the lack of a widely accepted rubric for argumentation assessment. As Mr. Jack stated, the students would not accept the importance of argumentation unless their performances in argumentation are formally assessed and acknowledged. It is not enough to simply require argumentation in state or national standards. Argumentation needs to be officially added as one contributor to students' achievement in science learning. However, the assessment of argumentation is a complex task (Osborne et al., 2004) so the design of a reliable and applicable rubric requires sustained efforts.

The other barrier is the role of a teacher's authority in dialogic argumentation. In this study, Mr. Jack struggled about his position in argumentation that his presence could potentially ruin students' argumentation and his absence could probably lead to students quickly reaching a conclusion to finish a task. In fact, high school students are at a transition stage from dependent to independent learning. They mainly rely on their teacher to acquire both scientific content knowledge and science learning skills (Hazari, Sonnert, Sadler, & Shanahan, 2010). Their thoughts are easily swayed by their teachers (Sadler & Zeidler, 2005). The heavy reliance of high school students on their teachers in science learning has put science teachers in a dilemma about argumentation. On one hand, teachers sponsor student argumentation. On the other hand, teachers' over involvement can jeopardize student argumentation. In other words, teachers can function as both the driving force and the barrier to argumentation implementation. How to keep the balance has become a challenging task for science teachers.

In response to the barriers listed above, we can apply the methods suggested by previous literature, such as developing long-term professional development projects for science teachers on the knowledge of argumentation (Osborne et al., 2013) and undermining teachers' mindset that argumentation is a higher-order thinking skills that comes after the mastery of content knowledge or that is only appropriate for high-achievement students (Zohar, 2007). Science teachers can diminish their power of authority to a level that students can compete with by taking the role of facilitators who connect opinions of different individuals (Zohar, 2007) or guiders who explore side-by-side with students (Tabak & Baumgartner, 2004). Teachers need to avoid depriving students of their opportunities of engaging in argumentation through over-inferring students' words or reasoning for them. These methods have been proven effective by empirical evidence so they have pointed the direction for educators and teachers about the long-term work with argumentation implementation.

These methods have also been claimed to require sustained efforts (McNeill & Knight, 2013; Osborne et al., 2013). However, it does not mean that argumentation can only take place in science classrooms after the task of teachers' professional development has been accomplished. Despite the barriers in this study, we made achievement in enhancing the students' participation in dialogic argumentation and promoting Mr. Jack's knowledge of assessment. Mr. Jack also prompted the students' argumentation by taking the role of a devil's advocate. Thus, argumentation can be performed meaningfully in a traditional teacher-centered science classroom context.

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