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Addressing Student Diversity in Science Classroom: Exploring Topic-Specific Personal Pedagogical Content Knowledge of High School Teachers

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Abstract: The student diversity in today's science classrooms presents challenges as well as learning opportunities for students and teachers. This research examines topic-specific personal pedagogical content knowledge (pPCK) of high school teachers as it relates to addressing student diversity in their science classrooms. A narrative inquiry approach was adopted to study four science teachers' experiences of teaching science, considering teachers' pPCK as an accumulation of experience. Narrative data was collected through interview conversations with these teachers about their experiences of conceptualizing and teaching force and motion topics to diverse groups of students in their science classrooms. The focus of these conversations was the day-to-day practice of participant teachers about making force and motion topics accessible to diverse learners. Using pedagogical content knowledge (PCK) as a conceptual framework, the narrative data were analyzed to explore how these teachers negotiated their content knowledge and knowledge of student diversity in shaping their professional knowledge of science teaching. The findings revealed that topic-specific pPCK of partcipant teachers was sourced in student diversity present in their science classroom, and its development underpins various processes to connect different types of knowledge. This research suggests considering teachers' knowledge of student diversity and how this impacts their planning and teaching of specific science content as an aspect of their topic-sepcific pPCK. Implications for science teacher education are included.

***Keywords**: Pedagogical content knowledge, Personal pedagogical content knowledge, Student diversity, Science teacher knowledge, Topic-specific pedagogical content knowledge.*

Introduction

Our world is becoming vastly diverse and is constantly changing, presenting diversity in many different aspects. Loreman et al. (2015) noted a wide range of differences within student populations in Canadian schools, and according to them, "Students come to school with a wide range of characteristics. They vary according to race, ethnicity, gender, age, and ability. They can also differ according to culture, ancestry, language, religious beliefs, sexual orientation, and socio-economic background" (p. 13).

To design learning experiences accessible for all students, teachers need to have the knowledge of student diversity and inclusive practices (Lee & Luykx, 2007). However, research shows that teachers face challenges to address student diversity and create inclusive learning environments (Avramidis & Norwich, 2002; Damianidou & Phtiaka, 2018; Florian & Graham, 2014; Sagner-Tapia, 2018). One possible reason for this challenge is lack of preparation to address student diversity within pre-service teacher education programs, partly because of content-free instruction about student diversity and inclusion, as well as the absence of opportunities for pre-service science teachers to integrate the knowledge of science content and student diversity. This challenge gets more significant when they are teaching historically difficult science topics, such as force and motion, for inherited learning problems reported in research literature mainly because of student misconceptions (Clement, 1982;

diSessa, 1983; Driver et al., 1994; Halloun & Hestenes, 1985).

The presence of student diversity in today's classrooms warrants the need to study science teachers' professional knowledge as it relates to student diversity and inclusive practices. Pedagogical content knowledge (PCK) has been considered an important aspect of science teachers' professional knowledge, which, according to Shulman (1986), is a unique amalgam of teachers' pedagogical knowledge and content knowledge. Shulman, further defined PCK as "the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). Moreover, PCK is a "practical way of knowing," is mostly "homemade (Gudmundsdottir, 1991, p. 35), develops over years of experience, and is about how they have accumulated "wisdom of practice" (Shulman, 1987). Therefore, it is not different from personal and personal practical knowledge (Fenstermacher, 1994, p. 6). The experiential view of PCK coincides with the idea of pPCK as represented in the Refined Consensus Model of PCK, which is defined as a teachers' "personal knowledge and unique expertise about teaching a given subject area, resulting from the cumulative experiences with and contributions from students, peers, and others (Carlson & Daehler, 2019, p. 86).

Diverse student groups in classrooms provide challenges as well as opportunities for learning. Saravia-Shore (2008) noted that "this enormously diverse and ever-changing system has the power to serve as an invaluable resource for all others—students, teachers, and the community as a whole" (p. 44). Ethnically, culturally, and linguistically different students bring diverse perspectives and experiences, which "offer a powerful resource for everyone to learn more—in different ways, in new environments, and with different types of people" (Saravia-Shore, 2008, p. 44). For example, Hong and Scott (2004) suggested that the presence of diversity or, more precisely, diverse perspectives (gender and ethnicity) could enhance the students' ability to problem-solving. Similarly, growing diversity in today's classrooms "encourages the development and use of diverse teaching strategies designed to respond to teach students as individuals" (Saravia-Shore, 2008, p. 44).

In North America, it has become important to educate pre-service science teachers for student diversity, particularly, cultural diversity (Huanshu, 2018). Despite calls for change, many "teacher education programs in Canada do not require pre-service teachers to "take a course on how to support, work with or include diversity (in all its forms) within their pedagogical practices" (Vanthuyne & Byrd, 2015, p. 530). The latest handbook of research on teacher education recommended that teacher education programs should provide the learning opportunity to help pre-service teachers integrate the knowledge of student diversity and school subject areas to prepare future teachers to take the challenge of "teaching for diversity and change" (Chou & Sakash, 2007, p. 526). However, teacher education programs that require pre-service teachers to take courses on student diversity and inclusion, barely provide the opportunities to integrate this knowledge with school subject areas (e.g., science and mathematics). Without this preparation, science teachers perform this task on the job, many time through trial and error, resulting into the accumulation of experience, termed as personal knowledge or personal practical knowledge (Elbaz, 1983; Clandinin & Connelly, 1995) and is close to the idea of pPCK (Carlson & Daehler, 2019).

The current study aims to understand science teachers' pPCK at the topic level (topic-specific pPCK) as it relates to student diversity based on their accumulated experience of engaging in teaching and making force and motion topics accessible to their students over the years. The following questions guided this research study: 1) How do science teachers make force and motion concepts accessible to diverse learners? 2) How do science teachers negotiate their conceptual understanding of force and motion topics and knowledge of student diversity to shape their professional knowledge?

Literature Review

This study draws on existing literature to understand (i) teacher knowledge as it relates to addressing student diversity in a science classroom, (ii) the role of student diversity in PCK, and (iii) the place of teacher knowledge in teacher education. Moreover, a summary of the literature on difficulties of learning force and motion is added to justify the selection of topics for this research. The next four sections outline the relevant literature to warrant this study.

Teacher Knowledge and Student Diversity

Teachers' professional knowledge emerges from their actual teaching that informs their practice (Hiebert et al., 2002, p. 3) and influences their actions in explicit pedagogical situations (Brown & McIntyre, 1993). This type of teacher knowledge is described using terms such as practical knowledge (Elbaz, 1981; 1983), personal knowledge (Lampert, 1985), experiential knowledge (Clandinin, 1985; 1988), and personal practical knowledge (Clandinin & Connelly, 1995; 1996). According to Verloop et al. (2001), knowledge of practice should be included in the "knowledge base [for the teaching profession] along with formal propositional knowledge" (p. 441) because it has the potential to guide pre-service teacher education. There is ample research reporting the problems that science teachers face while teaching students from diverse backgrounds. Therefore, there is a need to study teacher knowledge about addressing student diversity when teaching specific science content, to document a repertoire of strategies used by classroom teachers.

To provide accessible and inclusive science instruction to students from diverse backgrounds, science teachers require knowledge of the varied backgrounds of specific groups of students to address their particular learning needs. If teachers are not aware of the various cultural, racial, and linguistic backgrounds of their students, they are unable to reflect on how diverse backgrounds of students affect their educational experiences and thus fail to provide effective instruction (Cochran-Smith, 1995). To provide inclusive science instruction, recruiting science teachers from diverse backgrounds may help. However, Ladson-Billings (1995) believed otherwise, that matching teachers' backgrounds with students' backgrounds is not achievable. Therefore, she suggested helping science teachers in developing knowledge of their students' diverse backgrounds to provide more equitable and accessible science instruction. According to Lee and Luykx (2007), science teachers, in addition to knowing science content and science processes, should know the "ways in which academic content and processes may articulate with students' own linguistic and cultural knowledge [and] pedagogical strategies appropriate to multicultural settings" (p. 182). Moreover, understanding the impact of a curriculum that disregards students from certain backgrounds, thereby limiting their learning opportunities, is the key to effective teaching in multicultural classrooms.

Many strategies and models have been recommended to address student diversity in classrooms. These include multicultural education (Banks, 1993), culturally relevant pedagogy (Landson-Billings, 1994), and culturally responsive teaching (Gay, 2010; Garcia, 2005). Most of these strategies acknowledge the presence of multiple cultures within classrooms and schools, and aim at allowing crossing cultures on the part of students as well as teachers. To address student diversity in the science classroom, Loreman et al. (2015) recommended more personalized approaches to teaching and learning. Aikenhead (1996) asserted that cultural border-crossing is a precondition for learning science in a multicultural classroom, and suggested incorporating aspects of "other cultures" in science classrooms to make the topic accessible to all science learners. Shapiro (2015) invigorated the role that sociocultural perspectives play in a pedagogical situation where students engage in learning science when teachers "critically consider the personal, emotional, intellectual, cultural, social, and linguistic activities" (p. 366). According to her, to create inclusive science learning, teachers need to develop an understanding of the following: (a) students' differences regarding their experiences in learning science; and (b) creating supportive and interactive communities in science classrooms. She asserted that "to understand best the needs of diverse learners, teachers must build a deep understanding of the backgrounds and characteristics of all the children in their care" (Shapiro, 2015, p. 386).

Student Diversity and PCK

Subject matter knowledge (SMK) alone is insufficient for teachers to provide meaningful learning to diverse students in a science classroom. Howard and Aleman (2008) identified the need for "accurate command of the SMK in ways that can be communicated to diverse learners" (p. 161), which includes presenting the science content in multiple ways (Grossman, 1990; Shulman, 1986). Therefore, they implicitly recommended PCK as a prerequisite knowledge for addressing student diversity. Howard and Aleman (2008) identified the essential knowledge, skills, and dispositions of teachers for them to be able to teach in a diverse society. According to them, a science teacher needs to understand: (1) the subject matter and its required PCK; (2) knowledge of effective practices for teaching in diverse settings; and (3) the development of critical consciousness. Any effort to develop pre-service science teachers' capacity for diverse learners must include a continued discussion regarding PCK (Howard & Aleman, 2008).

Shulman's (1987) conceptions of PCK also implicitly included diversity as an important aspect. He defined PCK as "blending of content and pedagogy into an understanding for how particular topics, problems, or issues are organized, represented and adapted to the diverse interest and abilities of the learner, and presented for instruction" (p. 8). However, to date, diversity has not been considered a distinct component of PCK; rather, diversity is generally subsumed under the *knowledge of students* category and is usually limited to the understanding of student learning. Magnusson et al. (1999) interpreted 'knowledge of students' as the teachers' knowledge of their students' understanding of a given topic, including *knowledge of the requirement of learning* and *knowledge of areas of* *student difficulty*. The current focus on students' *understanding* of science misses many other aspects of student diversity that affect their learning. Kaljo (2014) introduced a new term "culturally relevant PCK" in the context of subject-specific pedagogies labs designed to prepare future teachers for urban schools to embrace student diversity present in these schools. These pedagogies labs were designed in Biochemistry, Environmental Sciences, Mathematics, and Political Science. There is a need to explore science teachers' professional knowledge further as it relates to student diversity, to advance our understanding of teachers' topic-specific PCK (TSPCK).

PCK and Force and Motion

Topics related to force and motion are included in K-12 science curricula around the globe, and consider difficult to understand by pre-service science teachers due to their abstract nature (Azam, 2018). Secondary students, university students, and pre-service teachers (Gunstone & Watts, 1985) are reported to have alternative ideas about force and motion topics. Some of the alternative ideas held by science teachers are similar to the ones held by secondary school students. Some of these alternative ideas include: (i) a force is exerted by an agent in direct contact (Halloun & Hestenes, 1985), (ii) if there is no motion, then there is no force acting (Clement, 1982), (iii) force causes motion in the direction of the force, and (iv) a moving object has a force within it that keeps it going (diSessa, 1983). These alternative ideas may hinder student learning of these topics and make it challenging for teachers to teach these topics. Therefore, the literature on students' alternative ideas identified the need for science teachers to have a conceptual understanding of these ideas, and a repertoire of strategies to allow conceptual change for their students. The scarce research on science teachers PCK related to force and motion also emphasized the need for a deeper understanding of force and motion, including student potential alternative ideas, and appropriate instructional strategies to teach these topics effectively (Alnozo & Kin, 2016; Loughran et al., 2004).

Theoretical Perspectives

The current research underpins the theoretical construct pedagogical content knowledge (PCK) introduced by Shulman (1986) and three processes of PCK development identified by Marks (1990).

Shulman (1986, 1987) conceived the theoretical construct PCK at the intersection of content knowledge (CK) and pedagogical knowledge (PK). Many educational researchers in the area of science education (for example, Gess-Newsome, 1998; Grossman, 1989; Hashweh, 1987; Lee &Luft, 2008; Loughran et al., 2001; Magnusson et al., 1999; Mark, 1990; Park & Oliver, 2008; Tamir, 1988) expanded and illustrated this complex construct, which resulted in several PCK models. Despite declaring PCK, a topic-specific knowledge (Park & Oliver, 2008; Loughran et al., 2001, 2004; Kind, 2015; van Driel et al., 1998), PCK researchers had less focus on deliberating this characteristic in PCK models. The first PCK Summit brought some consensus to PCK conceptualization and introduced the idea of topic-specific professional knowledge (TSPCK) within which PCK exists (Gess Newsone, 2015), highlighting the topic-specific nature of PCK. The Refined Consensus model (RCM), further clarified PCK, by considering it as collective (cPCK), personal (pPCK) and enacted (ePCK) PCK (Carlson & Daehler, 2019).

Despite these collective debates on science PCK, researchers have focused on conceptualizing TSPCK by offering specific TSPCK models (Azam, 2015, Azam, 2019; Mavhunga, 2014) to capture the interactions of various knowledge bases. Inspired by Geddis and Woods (1997), Muvhunga (2014) conceptualized TSPCK as a transformation of SMK in a particular topic, and identified five components of TSPCK: (i) learners prior knowledge, (ii) curriculum saliency, (iii), what makes the topic easy or difficult to understand, (iv) representation into powerful examples, and (v) conceptual teachings strategies. Her visual model of TSPCK depicts the relationship between these five components (Mavhunga & Rollnick, 2011).

The literature on PCK shows that PCK is not always a result of the transformation of SMK. According to Marks (1990), a transition from SMK to PCK involves three processes: *Interpretation*, S*ynthesis*, *and Specification*. *Interpretation* is close to what Shulman (1987) called *transformation*, Ball (1988) called *representations*, *and* Veal and MaKinster (1999) named "translation." The process for transition from other knowledge categories to PCK is *synthesis* where subject matter knowledge and general PK or any other two or more knowledge components combine to become part of PCK. Mark (1990) also found that some aspects of PCK are derived from general PK, and he called this process as *specification*, which helps the transition of general PK into PCK through the process of specification. These foundational ideas presented by Shulman and colleagues can be considered to reveal aspects of science teachers' TSPCK.
The following sections provide an overview of these three PCK processes as conceived in science education research.

1. The processes of Interpretation or transformation of SMK into PCK became popular when Shulman's (1986, 1987) conception of PCK was unpacked by construing his definitions. For example, Geddis et al. (1993) considered PCK as the knowledge that assists in transforming SMK into forms that are accessible to students, and Carter (1990) viewed PCK as what teachers know about SMK and how they transform that knowing into curriculum events in their classrooms. Mavhunga (2014) used the idea of transformation to define TSPCK, and used conceptualization of PCK by Geddis et al. (1993) to inform their TSPCK model.
2. The process of synthesis, as conceived by Mark (1990), is most commonly called integration, and became popular when the concept of PCK started expanding and researchers introduced new teacher knowledge components (e,g., knowledge of curriculum, knowledge of instructional strategies, knowledge of goals, knowledge of student understanding, knowledge of assessment, knowledge of context, knowledge of media or teaching resources, knowledge of subject matter) as constituent parts of PCK, based on empirical research (Hashweh, 2005; Lee & Luft, 2008; Loughran et al., 2001; Park & Oliver, 2008) or personal experiences (Abell, 2007; Cochran et al., 1993; Magnusson et al., 1999, Gess-Newsome, 2015). At the center of this expanded view of PCK is *integration* (Loughran et al., 2006; Park & Oliver, 2012; Van Driel et al., 2002) or synthesis (Mark 1990; Hashweh, 2005).
3. The process of specification helps the transition of general PK into PCK as a result of interaction with a particular content knowledge. This process has not received much attention from the science education researchers.

Mark's (1990) distinctions pointed that the prevailing conception that TSPCK is derived only from SMK is not the only reality, but other possibilities need to be considered for any conceptualizations of TSPCK.

These three processes informed my understanding of TSPCK related to student diversity, and assisted in analyzing participant science teachers' experiences to reveal their pPCK of teaching force and motion topics as it relates to student diversity. Figures 1a, 1b, and Ic present my understanding of the processes of interpretation, specification, and synthesis of conceptual understanding of force and motion topics and knowledge of student diversity resulting in TSPCK. Figure 1a shows the processes of Interpretation where teachers transform their content knowledge understanding of force and motion (CK) to provide an appropriate learning experience to address student diversity (PK)—illustrated by an arrow from CK to PK—resulting into their TSPCK as it relates to student diversity. Figure 1b depicts the process of synthesis, where both CK and PK are integrated—illustrated by a double arrow—to result in their TSPCK related to student diversity. Similarly, Figure 1c shows the process of *specification,* where knowledge of student diversity (PK) is transformed in response to specific content knowledge understanding (CK)—represented by an arrow from PK to CK—resulting in their TSPCK related to student diversity.

I have focused only on two knowledge categories here for making these processes visible. However, I acknowledge that in pedagogical situations, many knowledge categories combine to become a part of teachers' PCK.

Figure 1a

pPCK Related to Student Diversity as Interpretation

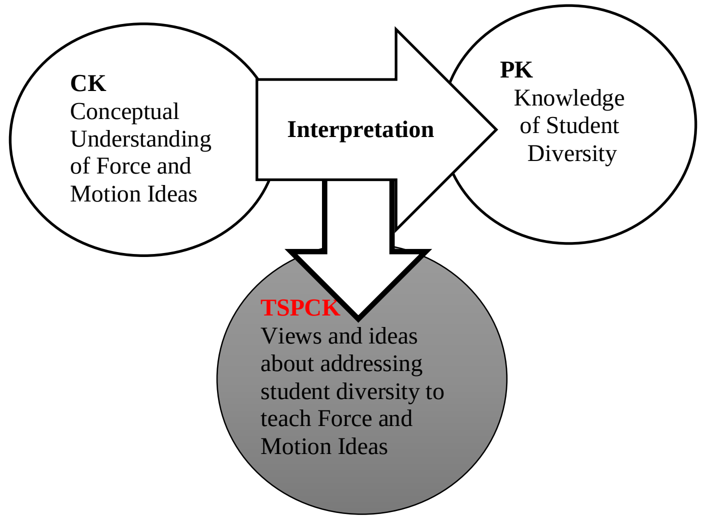


Figure 1b

pPCK Related to Student Diversity as Synthesis

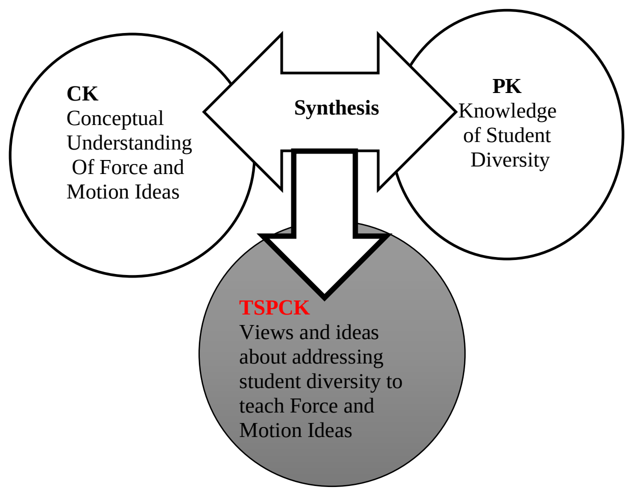
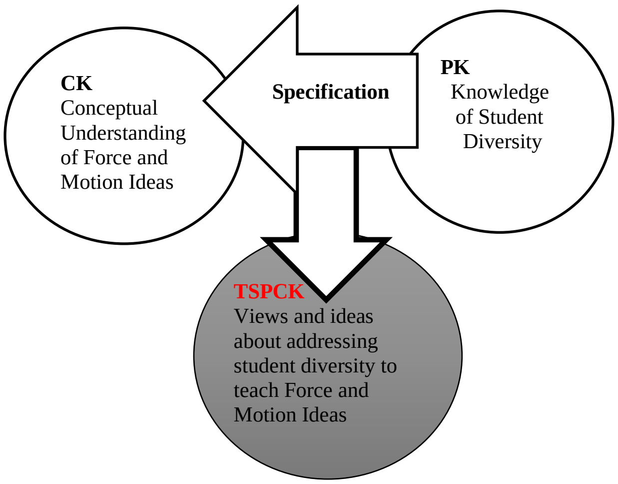


Figure 1c

pPCK Related to Student Diversity as Specification



Methodology

This research aimed to understand science teachers' pPCK at the topic level as it relates to student diversity in their classrooms, which was conducted as part of a large research project on studying science teachers PCK through their stories. According to Carlson and Daehler (2019), pPCK is a teachers' "personal knowledge and unique expertise [about teaching a science topic] resulting from the cumulative experiences" (p. 86). To study the accumulative experiences of teachers, Narrative Inquiry is recommended as an appropriate methodology ((Clandinin & Connelly, 2000) to study experience. Therefore, a narrative inquiry approach was adopted to study participant science teachers' accumulation of experience. Considering participant science teachers knower and sources of curriculum decisions regarding student diversity and making force and motion topics accessible to diverse learners in their classrooms, their experiences of teaching force and motion topics were captured through their narratives. A particular focus was on examining the experiences of these teachers sourced in their day-to-day practice of including diverse learners while teaching a specific science topic over time. It was expected that narratives of these accumulated experiences would yield strategies that were effective in this regard, inform science teaching practice, and topic-specific pPCK as it relates to student diversity.

Participants

Four science teachers, Kevin, Jason, Monica, and Dave (Pseudonyms) working in a western province of Canada, participated in this study. Initially, seven high school science teachers were contacted whom colleagues and the local school boards introduced, so these teachers were conveniently available and willing to share their stories of teaching fore and motion in detail. Also, the study purposefully focused on these four science teachers to maximize "variation in experience and descriptions using participants from contrasting milieus and background" (Hallberg, 2006, p. 143). The participant teachers worked in four schools from different communities with ethnically and linguistically diverse groups of students. Two of them (Kevin and Monica) taught in junior high schools (Grades 7-9) while the other two (Jason and Dave) taught in senior high schools (grades 10-12). Table 1 presents the participant teachers' qualifications and teaching experiences. None of the four teachers was prepared to teach specific science content to diverse students during their teacher preparation programs.

Table 1

Background Information of Participant Teacher

Name (Pseudonym)	Kevin	Jason	Monica	Dave
Gender	Male	Male	Female	Male
Education	BSc, BEd	BSc, Bed, PhD	BSc, Bed, PhD	BSc, BA, Bed
Science Majors	Biology	Physics, Chemistry	Maths/Biology	Biology/Sociology
Teaching Subjects	G. Science, Maths	G. Science, Physics	G. Science, Maths	G. Science, Biology
Teaching Grades	7, 8, 9	10, 11, 12	7, 8, 9	10, 11, 12
Teaching Years	8 Years	2 Year	14 Years	15 Years

Data Collection & Analysis

Narrative inquiry is rooted in "interrogating aspects of teaching and learning by storying experience" (Lyons & LaBoskey, 2002, p. 21). To investigate aspects of the participant teachers' teaching, narrative data were collected through interview conversations using a semi-structured protocol. Each teacher was interviewed two to three times, while each interview lasted for 90 minutes to two hours. During these interviews, stories of their experience of conceptualizing and teaching force and motion topics to a diverse group of students in their science classes were invited. The example questions asked included: How does the range of students' backgrounds affect your teaching of the concept, force?, How do you help students from various language backgrounds in your class while teaching them about the concept of force? Do the various cultural backgrounds of students in your classroom affect your planning about how to teach the concept of force? How? The researcher also kept field notes to clarify information collected from the teachers. The interview conversations with teachers were audio-recorded and then transcribed to verbatim into written texts and used as sources of data.

A three-step process was used for the *analysis of data*. First, I used the *analysis of narrative* technique (Polkinghorne, 1995). To assist the analysis of narrative process, I carefully reviewed the transcripts of the interview conversations to identify pedagogic episodes that are narrative fragments—small pieces of narrative data encompassing inclusive strategies used by the participant teachers about addressing student diversity and making force and motion topics accessible to all learners in their classrooms. I reviewed the transcript at least three times to ensure that all relevant narrative fragments were considered. I identified multiple pedagogic episodes for each participant teacher. These knowledge entities are considered topic-specific pedagogical constructions (TSPC), and a collection of these TSPCs embodies pPCK of teachers (Hashweh, 2005). Second, I used the *narrative analysis* technique (Polkinghorne, 1995), also called as narrative configuration, to weave these pedagogic episodes together into a coherent story for each participant teacher, representing examples of their pPCK related to student diversity. Third, I used Mark's (1990) three processes (interpretation, specification, and synthesis) described above, as an analytical framework, to examine which PCK process was involved in their stories of teaching force and motion topics and addressing student diversity (For details about adoption of Narrative Inquiry approach, and narrative analysis process see Azam (in press). Table 2 provides a summary of these pedagogic episodes as well as the PCK process involved in that episode. To achieve trustworthiness, I used member checks, as suggested by Lincoln and Guba (1985). The intention was to confirm and authenticate participant teachers` voices presented in their narratives.

Findings

In this section, first, I present a summary of the pedagogic episodes identified to present how participant science teachers made force and motion concepts accessible to diverse learners. These pedagogic episodes represent narrative fragments revealing aspects of participant science teachers' pPCK of force and motion topics as it relates to student diversity. Also, the processes (interpretation, specification, and synthesis) involved in each pedagogical episodes are identified (see Table 2). Then I provide detailed examples of three pedagogic episodes, as presented in participant teachers' narratives, to highlight each of the three processes in shaping their pPCK.

Example of Topic-specific pPCK Related to Student Diversity as Specification

The participant science teachers revealed that some aspects of their pPCK related to student diversity were derived from their general PK, through the process of *specification*. Here, I present some excerpts from Dave's story of teaching force and motion as examples of specification.

> Dave said that to address his students' different learning styles, "I try each day to have something for my visual learners, my auditory learners, and my kinesthetic learners." To achieve this, he explained, "I always have hands-on activities [for kinesthetic learners] . . . Something I show to them [for the visual learners], and then I talk them through examples [for auditory learners]." Dave has developed this three-dimensional framework and used this framework for his day to day science instructions.

Dave is using the term learning styles; however, the way he is using it is close to one of the universal design for learning (UDL) principles, which provides multiple means of representation to engage students in a science topic.

Dave further provided an example where he used the above three-dimensional framework to explain the concepts of distance and displacement, through the process of specification. He asked students to walk in a certain direction to draw a difference between distance and displacement (kinesthetic), drew both the pathways on the board (visual) to show the difference, and engaged students in a discussion using thoughtful questions to explain the concepts of distance and displacement (auditory).

Table 2

Summary of Pedagogic Episodes Representing TSPCK and the Processes Involved

Student Diversity	Pedagogic Episodes	Teacher	PCK Process
Student background/ Learning styles	Provided students with diverse learning experiences: kinesthetic (walking in the classroom to draw a difference between distance and displacement), visual (draw both on the board), and auditory (discussion through questions)	Dave	Specification
	Used a variety of ways to teach a topic to engage the auditory and visual learning styles of students. These ways include: Writing information on the board (force is push or pull). Describe an example so that they can listen to that information (making students push or pull objects and ask questions). Showing them a diagram/picture (pushing a door or pulling a door)	Monica	Specification
	Check the level of students' understanding (about force) before teaching them about Newton's third law.	Jason	Specification/ Synthesis
Language Background	Helped students understand the meanings of science words that are critical to describe force and motion ideas.	Jason	Interpretation/Synthesis
		Monica	Interpretation/Synthesis
	Helped then build word bank about force and motion contest.	Dave	Specification
	Provided students different opportunities to learn the material (represent the concept of force in multiple ways) to include all the learners in a science class, whether they are coded, ESL, or gifted.	Monica	Interpretation/Specification
	Used kinesthetic activities to make ESL students move and think, instead of talking.	Dave	Specification
	Used graphs purposely for teaching motion concepts, such as speed, velocity, and acceleration in order to help ESL students' learning.	Dave	Interpretation/Synthesis
Cultural/ethnic background	Helped student who have problems with understanding a problem for the reason that a local cultural image is used. For example, a force and motion problem where an example of Evil Knievel crossing the buses have been used.	Jason	Synthesis
	Used examples of scientists from many different cultures who have made significant contributions in the areas of science (force and motion).	Monica	Specification
	Providing students opportunities to explore bridges from other countries to make an understanding of force and structures relevant for ethnically and culturally diverse learners.		Interpretation
Indigenous Students	Used example of students walking different directions and figuring out the difference between distance and displacement through this activity	Dave	Interpretation
Diverse experiences or Socio-economic status	Used relevant examples of machinery in a rural setting for teaching about simple machines to students with a rural background.	Kevin	Specification
	Considering examples such as driving cars, and sitting in a place according to the socio-economic status of students.		
Physical Disabilities	Helped a hearing-impaired student to learn about force and motion topics through the use of hearing aids.	Jason	Specification

> Dave explained one such activity that he uses to teach about distance and displacement, two important concepts in Kinematics. He asks "two students to stand up . . . [and] walk around the class. [He] gives them different directions, for example, 'you walk five meters' . . . [and] 'you walk two and a half meters east and two and a half north', and tell me the difference." He further explained that the other students in his class "watch these [two] students walk around the classroom" and contribute to the discussion. According to Dave, "Then we as a class explore the difference between distance and displacement." Through this activity, his intention was to help students explore the difference between distance and displacement. Therefore, he drew the pathways on board and asked questions to draw students' attention to the total distance covered (2.5 m +2.5 m) and the shortest distance covered from Point A to B.

The above excerpts from Dave's story present an aspect of Dave's general PK (three-dimensional framework), which he used to stipulate his teaching of force and motion topics (CK) through the process of specification.

Example of Topic-specific pPCK Related to Student Diversity as Interpretation

The participant science teachers' stories exposed that some aspects of their pPCK related to students' diversity were derived from their SMK, through the process of interpretation or transformation. Here we present some excerpts from Monica's story of teaching force and motion, as examples of interpretation.

> During fourteen years of teaching science at the junior high school level, Monica appears to change from a traditional science teacher to an inquiry orientated teacher. Monica shared her insecurities about teaching force and the whole unit on structures and forces, during the early days of her teaching career. Monica highlighted the need to understand the science content knowledge involved before teaching it to the students. Based on her continuous effort to clarify the conceptual understanding involved in the teaching force, particularly in the context of structures, Monica described her thinking in the following excerpt from her narrative.
>
> Monica used the standard definition of force, that force is a push or pull, when she described her understanding, noting that "when you [are] pushing something or pulling something, that is a force." . . . . Monica thinks that a student understands the concept force only if they know what a force does and are able "to show" this. By this, she means that her students should be able to demonstrate a force, wherein she expects her students to "actually . . . physically use a desk or move something . . . [and say that they are] . . . pulling it or . . . pushing it." She also wants them to understand that "Newton is the unit for [measuring] force."
>
> According to Monica, in addition to the idea that force is a push or pull, "you [can also] look at how force can impact objects." And based on this impact, we can differentiate the different types of forces. She suggested that

"force is a very general term . . . [and] you have to be specific. . . . So, you [should] use words like compression, compressive strength, bending force, or tension." Monica noted that there are four types of forces, which include, (i) compression force, (ii) torsion force, (iii) tension forces, and (iv) sheer force. . . . . In the context of the Structures and Forces unit, Monica wants her grade seven students to understand why structures fail, and what role forces play in strengthening or weakening a structure. She further explains that when creating structures, compression, tension and torsion are internal forces but that there are external forces as well, which may be responsible for a structural failure.

Monica has been teaching grade seven unit on forces and structures for many years. One of the activities that she uses to explain the impact of forces on different types of structures involves building structures and testing their strength:

> We talk about internal forces, . . . external forces, . . . metal fatigue, [and] . . . why structures fail. . . . [Students] will come up with ideas . . . when they are designing and testing [their structures] . . . [that they] need more support here . . . [and they] need to have a base there . . . [and they also] need to know why did [their] structure fail?

Monica said that her students "have opportunities . . . within the parameters to rebuild [their structures] so that they can apply their knowledge of internal and external forces. She elaborated that her students "come up [with] some amazing ideas . . . [about] where the deficiency is, and how to make it improved . . . by raising [a part of the structure], by supporting [a certain part of the structure], [or by knowing] . . . how much it weighs . . . , what is the load, and how much it is supposed to carry?"

Monica also claimed that she embraces a curriculum that recognizes, promotes, and enhances diversity in the science classroom. She shared an activity where she organizes curriculum to help her students become aware of the people and scientists from many different cultures who have made significant contributions in the areas of science. To include students from various cultural and ethnic backgrounds, Monica tries to "incorporate . . . different types of structures . . . globally." She said, "I push them to . . . research something in Dubai and go and research something in Turkey, or [something] in Asia, or [something] in China." By using this approach, Monica stated that she encouraged them to explore structures from their home countries. She wanted her students "to recognize that these famous buildings are not just in Europe and Western society, but famous structures are all over the world, going back to 1000 BC," and even in their home countries.

After clarifying and expanding her understanding of forces (CK), Monica learned about student diversity and inclusive education in her graduate studies. As a result, she embraced multicultural science education (a form of her PK) in her classroom, which influenced her teaching about forces and structures. Based on her new understanding of student diversity and multicultural education, she interpreted her content knowledge of forces and structures by introducing popular structures from around the around the world to help include her diverse group of students who have come to Canada from different counties.

Example of Topic-specific pPCK Related to Student Diversity as Synthesis

The participant science teachers' narrative revealed that some aspects of their pSPCK related to student diversity are results of a combination of their SMK, PK and/or other forms of teacher knowledge, through the process of synthesis. Here we present some examples of synthesis, as presented in Jason's story of teaching force and motion topics. Jason has been teaching in a school where many of his students are ESL learners. He did not receive any special training on teaching ESL learners. However, he has developed his personal practical knowledge about issues and problems these ESL learners face in understanding physics. The following excerpts from his narrative present his understanding of helping ESL students solve physics numerical problems.

> Jason identified a problem that his English as Second Language (ESL) students usually face problems involving their inability to understand the cultural images used in numerical problems related to force and motion ideas. He pointed out that many of his students with diverse cultural backgrounds fail to understand these local non-inclusive cultural images, and as a result, fail to break apart the problem, which is critical to solving it. Jason considered those who write such problems in physics and other sciences are partly responsible since they include only specific or local cultural images. This excludes many students and poses a serious problem for them when they try to solve these problems. Jason showed his concern that in an effort to make physics problems interesting by presenting novel scenarios; some test writers ignore the recipient. In his estimation, this is unfair to certain students.

Jason also described his deep understanding of physics problems and how physicists solve these problems. He has created specific strategies to help students decode the problem like a physicist. For example, (i) evaluating a force against three-step-criterion, (ii) identifying force in different situations, and (iii) solving force related problems using a four-step process.

Realizing that at a certain point, the push or pull criterion is not sufficient to identify and define forces, Jason developed the set of three criteria (force is a vector; force needs to act on something; every force needs to be applied by something). He introduces these criteria at the beginning of the unit, and then uses throughout the unit, whenever students need to clarify the concept of force. He provides his students free body diagram problems, and asks them to "itemize forces" on a given body in a given situation. Itemizing forces includes making a list of forces acting on the body and then identifying the type of force. After the students have listed and named these forces, he initiates a discussion by picking one of the forces from a student’s list and asking them to justify their answer. He expects his students to justify their answers using the three-step criteria discussed above to evaluate a force.

Jason stated that he has designed, and uses “a four-step process,” which he runs through to solve any force-related numerical problems systematically. It is as follows: (i) draw a free body diagram, (ii) choose a coordinate system, (iii) develop a table of components, and (iv) solve the problem using Newton’s laws of motion. Jason explained that he devised this process to help his students overcome their mistakes: “choosing their forces wrong, doing components incorrectly, or omitting a force entirely.” He communicated that he thinks this process also helps ESL students to be methodical, creative and imaginative before starting the actual mechanics of the numerical problems.

Here is an example of a specific problem that Jason called a culturally-specific physics problem to explain how he synthesized his knowledge of physics problem solving and his understanding of problems that ESL students will face for solving this problem, presenting his pPCK related to students diversity. Jason gave an example of one of these culturally-specific physics problems: “When Evel Knievel is looking to launch himself over [. . .] five school buses, if he needs to clear the buses, [and the distance between] each bus is 3 to 4 meters, to stop, how fast is he going to have to go as he leaves the ramp?” According to him, if students do not know who Evel Knievel is—that he rides motorcycles in huge, spectacular stunts—it is likely that they will not be able to understand the problem and solve it, which is unfair to those students.

> Jason called this a “decoding problem” and described this as a process “from [the] problem that is written on the page to actually. . . deal[ing] with it as a physics problem.” Jason indicated that knowing this process of “break[ing] this problem apart . . . [the way a] physicist [would] do it, is what makes you a physicist or mathematician, or chemist.”

Jason, being a caring teacher, helps his students in any such situation, by using his specially designed procedures to solve physics problems, and encouraging his ESL students to ask if they do not understand any word in a given problem. He emphasized how he helps his students in such a situation, saying I make sure my students know that I, no matter what the circumstances are, no matter whether it is a test or whatever, I will stay with them as long as it takes for them to understand [and] for us to agree on what the problem means. Because until they understand what the problem means, they cannot solve it.

Discussions

The science teachers’ narratives revealed the diverse backgrounds of students present in their science classrooms and how these backgrounds impacted both students’ learning and teachers’ teaching. These narratives also reveal science teachers’ topic-specific pPCK related to student diversity, an aspect of their topic-specific professional knowledge developed on the job as a result of exposure to student diversity in their classroom and experience of teaching diverse student populations force and motion ideas. As described above, these teachers did not have any formal training to address student diversity while teaching science, so, in this case, the presence of student diversity brought opportunities for learning for participant teachers and helped them develop diverse teaching strategies to engage all students (Saravia-Shore (2008).

After comparing the experiences of four science teachers, it was evident that the teachers who were exposed to student diversity in their science classroom inclined to develop their knowledge of student diversity. Kevin had fewer experiences of dealing with student diversity in his classroom as compared to Jason, Monica, and Dave. Later three had been teaching in schools where student populations are new or settled immigrants, who come from diverse ethnic, cultural, religious, linguistic, and economic backgrounds. Dave further had the opportunity to participate in discussions and workshops on inclusive science education, which provided him exposure to the diverse students' learning needs and ways to help them learn science. These observations showed an agreement to the existing literature that asserts that presence of diverse student group in classrooms provide opportunities for learning (Saravia-Shore, 2008), and in this case, diverse student groups acted as living learning resources for these science teachers. These resources provided learning opportunities for participant science teachers to think and plan their curriculum related to force and motion ideas to make science learning around these topics accessible for all learners in their classroom, hence developing their professional knowledge for teaching force and motion to diverse students. This also explained why Kevin did not describe many strategies to teach force and motion topics to diverse students, and had less developed pPCK related to student diversity as compared to other three science teachers.

According to Saravia-Shore (2008), growing diversity in today's classrooms "encourages the development and use of diverse teaching strategies designed to respond to teach students as individuals" (p. 44). Monica, Dave, and Jason had the responsibility to teach science to new immigrants, who are still learning English as a second language. They reported both general as well as content-specific strategies to teach force and motion to ESL learners. The topic-specific strategies and inclusive practices of these teachers show how they adapted their content knowledge to help diverse students learn it, which represents their pPCK. Each science teachers' pPCK related to student diversity was idiosyncratic and emerged as a result of their unique experiences regarding student populations in their classrooms, which in turn also depended on the geographical location of the schools where they were appointed. Jason, Dave, and Monica had been working in schools that are located in predominantly new immigrant's areas, and hence, these schools have a high intake of new immigrant students. That is the reason all three of them had long or short experiences of dealing with students from various ethnic, cultural, and linguistic backgrounds. Kevin had been teaching in a rural area school for the last many years, and usually, new immigrants do not settle down in that area. He probably had never experienced dealing with a student from diverse linguistic and ethnic backgrounds. That may be a reason for not being able to share any strategy to include students from these backgrounds. However, Kevin was able to discuss some strategies and examples that he uses for his students from rural backgrounds, where Jason, Dave, and Monica did not mention this aspect of student diversity at all. This pointed to the pre-condition for developing pPCK related to student diversity, where teachers need to have experience of teaching students from diverse backgrounds while they are teaching specific science content to students. This had implications for pre-service science teacher education.

The development of topic-specific pPCK entails various processes: specification, interpretation, and synthesis. The analysis of narratives, using these three processes as an analytical framework, revealed how participants unified their content knowledge understanding of force and motion ideas with their knowledge of student diversity into their pPCK. Science teachers may enact their pPCK related to student diversity by (i) interpreting (modifying or adapting) the content knowledge, (ii) specification of the pedagogical knowledge, or (iii) synthesizing the content knowledge and knowledge of student diversity according to individual student's learning needs and using thoughtful instructional strategies. From this perspective, science teachers' topic-specific knowledge of student diversity, as a dimension of science teachers' pPCK, considers teachers' views and understating of students' diverse backgrounds and their efforts to make a specific science content accessible to all science learners in their classroom. This dimension of science teachers' topic-specific science pPCK is governed by science teachers' goal of inclusive science education.

Conclusion and Implications

To provide inclusive science education, the science teachers address diverse backgrounds of students while trying to help them understand specific science content, force and motion topics in this case. This, in turn, informs their knowledge base of teaching (force and motion topics) as well as knowledge about addressing student diversity in their classrooms. This topic-specific knowledge base contributes to their pPCK related to student diversity. To help pre-service science teachers develop topic-specific pPCK, they need to indulge in teaching and reflecting on teaching science topics. Similarly, to develop science PCK related to student diversity, they need to have those science teaching experiences with students from diverse backgrounds.

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