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Investigating Coherence among Turkish Elementary Science Teachers' Teaching Belief Systems, Pedagogical Content Knowledge and Practice

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Abstract: This study investigated comprehensive science teaching belief systems and their relation to science teachers' pedagogical content knowledge and teaching practices. Rokeach's (1968) belief system was used as a framework for representing the hierarchy among in-service teachers' teaching beliefs. This study employed a multiple case study design with three in-service science teachers. Cases were selected based on participant's personal epistemology. Data were collected through interviews and classroom observations. Content analyses showed that when science teachers presented characteristics of autonomous self-construal more than related self-construal, they had a more advanced personal epistemology. In addition, these beliefs shaped participants' conceptions of teaching and learning science as well as self-efficacy beliefs, knowledge and practice. Given these results, it is important for social psychologists to collaborate with science teachers to support their self-construal.

Keywords: science teaching belief system, self-construal, epistemological beliefs, conceptions of teaching and learning, self-efficacy beliefs, pedagogical content knowledge

Introduction

Science teachers' practices affect student learning. This has led researchers to examine methods to improve science teachers' practices to influence improvements in students' conceptual understanding of science. There are two different research areas that focus on this issue: teacher beliefs (Pajares; 1992) and teacher knowledge (Shulman, 1986).

Many researchers have investigated science teachers' beliefs and the effects of these beliefs on teaching behaviours (Pajares, 1992). Research shows that science teachers have different beliefs about teaching practices (Fishbein & Ajzen, 1975). This directed researchers' attention to belief systems rather than individual beliefs (Fishbein & Ajzen, 1975; Rokeach, 1968); however, there are continued discussions about which beliefs should be involved in a comprehensive science teaching belief system. Science teaching belief systems and the types of beliefs that are investigated are often more appropriate for Western cultures because the samples are usually Western teachers. Turkey is geographically and culturally located between Europe and Asia and simultaneously represents cultural characteristics from both civilizations. However, Western-based educational adaptations frequently neglect how Turkish culture differs from Western civilization. Given this concern, science teacher educators should develop culturally unbiased and comprehensive teaching belief systems. In addition, some researchers (e.g., Fang, 1996; Kane, Sandretto & Heath, 2002) suggested that it is important to examine teachers' beliefs and practices together because there may be inconsistencies between the beliefs and actual practices. Despite this clear suggestion, there is a need for more research in this area of science teacher education.

Research on teacher's knowledge is often based on science teachers' pedagogical content knowledge (PCK). Since being introduced by Shulman (1986) as a missing paradigm, science education researchers have shown increased interest in PCK. Currently, science teacher educators believe that teachers' PCK shapes their teaching decisions and practices (Magnusson, Krajcik & Borko, 1999). However, there is limited research that provides evidence for this association. There appear to be two primary reasons for this problem. The first is related to assessing a science teacher's PCK. The second challenge is related to the content that comprises a science teacher's PCK. To address the first problem, prominent scholars suggest that it is important to use qualitative research designs (Baxter & Lederman, 1999). For the second problem, it is important to differentiate between the content that should be included in and the factors that affect a science teacher's PCK. Currently, researchers appear to have reached a consensus that teachers' beliefs influence their PCK and that PCK should include a science teacher's knowledge about learners and representations.

Investigating the components and constructs that were described above will empower science teacher educators' visions of the relationships among their beliefs, knowledge and practices. First, research should examine the relationships among science teachers' beliefs to construct culturally unbiased teaching belief systems. These studies should include cultural variable(s). Second, research should investigate the relationships among comprehensive belief systems, PCK and teaching practices. We believe that culturally unbiased teaching belief models will allow scholars who are not from Western cultures to understand how to integrate Western variables into their educational systems. Therefore, research may have implications for both researchers and science teacher education programmes. Given this significance, this study investigated a comprehensive science teaching belief system in addition to its relation with science teachers' PCK and teaching practices. As such, we addressed two research questions:

1) To what extent do in-service science teachers' self-construal, epistemological beliefs, conceptions of science teaching and learning and self-efficacy of learning and teaching science construct a coherent science teaching belief system?
2) How do in-service science teachers' culturally unbiased teaching belief systems affect their PCK and teaching practices?

Theoretical Framework

Teacher Beliefs and Belief Systems

In general, beliefs are defined as an individual's subjective judgements about him/herself and the environment in which s/he lives (Fishbein and Ajzen; 1975). Researchers have claimed that teachers' beliefs effect their decisions and practices because beliefs act as filters for knowledge and practice (Pajares, 1992). In addition, teachers' beliefs are resistant to change (Kane et al., 2002); however, it is important that science teachers' educators attempt to change these beliefs. At this point, it is critical to investigate the hierarchy among these beliefs to decide which beliefs have more impact on science teachers' practices and which are resistant to change. Rokeach (1968) states that people have hundreds of beliefs that are aligned on a hierarchical, central-peripheral continuum that is both inevitable and valuable. That is, beliefs have a hierarchical order in which some are central, and these influence the peripheral beliefs. According to Rokeach (1968), people cannot live with a high number of equally important beliefs, which occurs when there is no hierarchy among beliefs. Although his seminal research attempts to provide both empirical and theoretical scholarship in psychology, there are few studies about the hierarchical order of teaching beliefs in the education literature regarding science teachers. In the teacher education literature, researchers sometimes find that teachers' expected beliefs and actual practices are not coherent (e.g., Kane et al., 2002). This may be due to ignorance for the hierarchy among these beliefs, which was stated by Rokeach (1968). He found that people have five types of beliefs. Types A and B encompass people's judgements about their nature of self. Type C beliefs are authority beliefs that correspond to judgements that should be accounted for to make the world more rational. Type D beliefs involve ideological beliefs, which are derived from authority beliefs. Finally, Type E beliefs include beliefs about taste and personal pleasure.

Rokeach (1968) states that central beliefs are connected to other beliefs; therefore, they are more resistant to change compared to peripheral beliefs. In addition, peripheral beliefs are derived from central beliefs. His research showed that Types A and B beliefs are more central than other beliefs because they relate to the nature of self. Of these, Type A is more important than Type B because the latter is based on a 'zero consensus.' Type C beliefs are more important than Type D beliefs because the latter is derived from the former. Finally, Type E beliefs are the most peripheral because they are weakly related to other types of beliefs. For science teacher education, no comprehensive research has presented this hierarchy and classification for science teachers' teaching beliefs. This study examines science teachers' self-construal as Types A-B beliefs, epistemological beliefs as Type C, conceptions of teaching and learning as Type D and self-efficacy of learning and teaching as Type E beliefs to construct our belief system model. The following sections will clarify the hierarchical relations among these beliefs.

Self-Construal

Self-construal includes people's beliefs and perceptions about themselves. It is a social construct that is culturally valued by a society; therefore, self-construal is affected by cultural values, including collectivism-individualism (Kağıtçıbaşı, 2007; Kitayama, Duffy & Uchida, 2007). According to social psychologists (e.g., Kağıtçıbaşı, 2007; Triandis, 1995), society's perspectives on independence and interdependence determine the characteristics of self-construal. For example, when independence is more valuable than interdependence for human relations in a society, then people are more likely to have autonomous self-construal. A reverse valuation increases the number of people who have similar self-construal. Kağıtçıbaşı (1996) objected to this dualistic categorization of self-construal and argued that autonomy and relatedness are not in opposition. Thus, people can simultaneously have both of these characteristics. She provides three types of self-construal: autonomous, related and autonomous-related. In general, autonomous people feel self-sufficient and independent from others, while people who have related self-construal are dependent on others, such as family members and authorities. This dependence causes related people to make decisions based on others' perspectives. In contrast, people who have autonomous-related self-construal feel independent and also have (close) relationships with others. Kağıtçıbaşı (2007) stated that qualitative methods, in which individuals are asked to define themselves, are an effective way to measure self-construal. Individuals' responses about their relationships demonstrate related self-construal, while descriptions about personal characteristics correspond to autonomous self-construal.

Self-construal may affect people's self-enhancement and achievement motivation (Kağıtçıbaşı, 2007). For example, research has shown that people who have autonomous self-construal have higher achievement motivation than people who have related self-construal. This study examined self-construal in the context of science teachers' belief system for two reasons. First, belief systems have a hierarchy, which was previously discussed. If we detect connections between self-construal and teaching beliefs, then we will be able to recommend self-construal education for science teacher education programmes. Second, there are cultural concerns in education systems. Constructivism drives contemporary science education; however, this theory relies on independence because it focuses on allowing students to independently construct meaning. However, this independence may create problems for science teachers who have related self-construal, who may view themselves as authority figures and believe that others should think as they do.

Personal Epistemology

Personal epistemology reflects people's beliefs about the structure of knowledge (i.e., certainty and simplicity) and how they come to know (i.e., source and justification) (Hofer and Pintrich, 1997). Research on personal epistemology reflects three different perspectives. The first tradition uses a developmental approach that began with the seminal work of Perry (1970), who presented empirical evidence that people have a dualistic stance at an early age. Based on a Piagetian view and a longitudinal observation, he stated that biological progress shifts people's personal epistemology to multiplicity, relativism and commitment within relativism. Among the followers of this tradition, Kuhn, Iordanou, Pease and Wirkala (2008) confirmed a three-stage categorization (absolutist, multiplist and evaluativist) that is parallel to Perry's (1970) stages. Absolutists believe that everything can be classified as right or wrong. As such, certainty is possible via direct observation. Multiplists believe in subjectivity and that certainty is not possible because of the subjective nature of knowledge. Finally, evaluativists believe that certainty is not possible but is approachable by justification through interpreting evidence.

The second tradition is multidimensionality and was introduced by Schommer (1994). Schommer (1994) objects to unidimensionality in epistemological beliefs and claims that personal epistemology encompasses epistemological beliefs, which are more or less independent. From this perspective, an individual may have sophisticated beliefs about certainty and naïve beliefs about the simplicity of knowledge. Schommer (1994) envisions five different epistemological dimensions, which are certainty, simplicity, source, quick learning and innate ability. Researchers have criticized the latter two dimensions and suggest that those beliefs relate to learning rather than knowledge and knowing. Schommer-Aikins (2004) accepted these criticisms. A sophisticated belief of certainty corresponds to the idea that knowledge is not certain, while naïve beliefs indicate that knowledge is certain. A sophisticated belief in simplicity suggests that knowledge includes related parts that have complex meanings; while naïve beliefs admit that knowledge has components that are not related. Finally, sophisticated beliefs in source indicate that knowing is possible through logic and experience, while naïve beliefs suggest that knowledge only resides in authorities, such as scientists and books. Using the developmental perspective, Hofer and Pintrich (1997) added a dimension of justification. Sophisticated beliefs in justification suggest that applying logic and interpreting evidence is required for knowing, while naïve beliefs indicate that consensus among authorities reflects knowledge. Muis, Trevors, Duffy, Ranellucci and Foy (2016) found that multidimensionality could not be observed during interviews with students from secondary through graduate school because the students could not articulate the differences.

The third tradition of personal epistemology specifies the domains. This perspective is grounded in the idea that people have domain general epistemic belief systems and that these beliefs are specified to domains when they are measured at task specific levels (Buehl, Alexander & Murphy, 2002). For example, Muis et al. (2016) found that students' epistemic views about psychology and mathematics were partially differentiated. However, they also indicated that this discrepancy primarily corresponded to students' limited experiences in these domains and the structure of their educational contexts.

There are two reasons that epistemological beliefs are important for science teacher educators. First, these beliefs are central to beliefs about learning and teaching (Brownlee, Boulton-Lewis & Purdie, 2002; Hofer & Pintrich, 1997). For example, Chan and Elliott (2004) presented empirical evidence that sophisticated epistemological beliefs allow pre- and in-service teachers to have constructivist teaching and learning conceptions. However, the results were not consistent for all of the dimensions of epistemological beliefs, which may have been due to cultural differences between Western and Eastern countries. Hofer (2008) also called for research to account for cultural factors in epistemic studies. In addition, research has found that epistemological beliefs affect students' learning (Bahçivan, 2015; Muis & Franco, 2009; Stathopoulou & Vosniadou, 2007). These findings should motivate science teacher educators to investigate the effects of personal epistemology on science teachers' teaching beliefs. Second, researchers (King & Kitchener, 2004; Muis et al., 2016) have found that personal epistemology is affected by educational contexts and interventions. Thus, it is important to investigate their effects on the science teaching belief system to create educational contexts that promote science teachers' epistemological progress.

Conceptions of Teaching and Learning

Conceptions of teaching and learning (COTL) comprise teachers' personal definitions of teaching and learning as well as their beliefs about how these should be processed (Chan and Elliott, 2004). Researchers have conduced phenomenological studies to label students' and (pre-service science) teachers' conceptions about learning (Bahçivan, 2014, Marton, Beaty and Dall'Alba, 1993; Tsai, 2004). Memorizing, increasing knowledge and performing science can portray these conceptions. In addition, several researchers (e.g., Koballa, Graber, Coleman & Kemp, 2000; Tsai, 2002) investigated pre-service and in-service science teachers' conceptions of teaching science and categorized them as transferring knowledge, interacting, and constructivist. Scientific studies on teachers' COTL have found similar categories for the traditional-constructivist scale, with slightly different labels. In addition, Koballa et al. (2000) and Tsai (2002) found that most (pre-service) science teachers' COTL were coherent. That is, when a science teacher has a constructivist conception of teaching, s/he also has a constructivist conception of learning. As such, Tsai (2002) referred to these conceptions as nested epistemologies. Based on these findings, Chan and Elliott (2004) validated a scale to demonstrate that in-service teachers' COTL could be categorized as traditional vs. constructivist.

An abundance of research has shown that pre-service teachers' COTL are related to their self-efficacy (Bahcivan & Kapucu, 2014; Eren, 2009) and epistemological beliefs (Bahcivan, 2014; Chan & Elliott, 2004). In addition, pre-service science teachers' COTL is related to their PCK (Bahçivan, 2014) and classroom practices (Koballa, Glynn, Upson & Coleman, 2005). With few exceptions, science teachers' sophisticated epistemological beliefs allow them to hold constructivist conceptions, which increase their teaching self-efficacy and positively relates to PCK. Unexpected relationships are often attributed to cultural tendencies (i.e., Bahcivan, 2014; Chan & Elliott, 2004).

The Self-Efficacy of Learning and Teaching

Self-efficacy is an individual's perceived beliefs and judgements about what they are able to perform and achieve based on their skills and knowledge (Bandura, 1977). Given this definition, science teaching efficacy refers to science teachers' beliefs about the extent to which they can manage and contribute to their students' conceptual understanding (Gibson & Dembo, 1984). In addition, efficacy for learning science refers to people's perceptions of the extent to which they can comprehend scientific concepts and solve real life problems (Pajares, 2002). Bandura (1977) presents four primary sources of efficacy beliefs: enactive attainments, vicarious experience, verbal persuasion and physiological states.

Research has shown that self-efficacy beliefs predict individuals' learning and teaching behaviours in science learning environments. For example, students' science learning efficacy beliefs are related to their motivation and academic achievement (Pajares, 2002). Efficacious students believe that they understand scientific concepts in a meaningful way. Similarly, Ramey-Gassert, Shroyer and Staver (1996) found that more efficacious science teachers believe that they can positively contribute to student's conceptual understanding and continue to teach when their students have misconceptions. In addition, science teaching efficacy beliefs are related to other beliefs, which comprise the science teaching belief system. For example, pre-service science teachers' science teaching efficacy beliefs are related to their conceptions of learning science (Bahcivan & Kapucu, 2014). Bahcivan (2014) also found that pre-service science teachers' sophisticated epistemologies positively contributed to their science teaching efficacy beliefs.

Pedagogical Content Knowledge

PCK was introduced in Shulman's (1986, 1987) seminal work. Shulman's first definition of PCK highlighted three characteristics. First, PCK is the knowledge of teaching that is specialized for a topic. Second, PCK comprises a teacher's instructional representations (i.e., demonstrations, analogies, illustrations). Third, PCK includes teachers' knowledge of how students learn the topic and includes awareness of learning difficulties and misconceptions. Shulman and colleagues presented PCK as a domain of teacher's knowledge base (Wilson, Shulman & Richert, 1987). However, they also mentioned that PCK is a domain that benefits from other knowledge domains. Therefore, PCK is a unique combination of different types of teacher knowledge and may represent the core of knowledge. Recently, several researchers have constructed different types of PCK models that include additional components (Hashweh, 2015). There is a group of models (i.e., Cochran, DeRuiter and King, 1993; Magnusson, Krajcik & Borko, 1999) that identifies the components that are included in PCK. Another group of models (i.e., Park & Oliver, 2008) clarifies the development of PCK. Developmental models include specific teaching beliefs [i.e., teacher efficacy beliefs in Park & Oliver's (2008) PCK model] as an interactive component in addition to the original PCK components. Although its structure lacks clarity, science teacher educators have attained a partial consensus. Lee and Luft (2008) compared all of the PCK models and found that all models included two components: knowledge of representations and knowledge of learners.

In addition to performing qualitative studies, PCK researchers have also attempted to measure this construct. Because there are no internationally valued standards for teaching a given topic, there are few quantitative assessment tools. Hill, Schilling and Ball (2004) validated a scale that uses multiple-choice items to measure mathematics teachers' PCK for certain topics. However, these researchers found that teachers' test taking skills and mathematical reasoning were effective for selecting the correct choices. In addition, Rohaan, Taconis and Jochems (2009) developed a multiple-choice scale to measure technology teachers' PCK, but the measure had low test-retest reliability (score of .39). Because it is important to collect different types of data to measure science teachers' PCK, Baxter and Lederman (1999) suggested adapting qualitative designs to assess science teachers' PCK. For example, Hashweh (2015) used a qualitative design to assess science teachers' PCK. Several types of data were collected, including interviews that focused on different aspects of PCK, sorting tasks and classroom observations. He also created a checklist to evaluate science teachers' organization of PCK that focused on its selected components. By triangulating the data, he obtained a detailed portrayal of science teachers' PCK.

Science teacher educators accept that PCK is the foundation of science teachers' practice; therefore, it affects their teaching behaviours (Magnusson et al., 1999). In mathematics education, Hill, Rowan and Ball (2005) found that mathematics teachers' PCK predicted their students' achievement. Furthermore, Bahçivan (2012) found that in-service science teachers' self-efficacy beliefs affected their PCK for teaching electricity. Park and Oliver (2008) found similar results. However, there are few studies that relate this construct to a comprehensive science teaching belief system and teaching practices.

Method

To ensure that a science teaching belief system explained participant's teaching practices, we first examined the coherence among teaching beliefs and then examined the relations between this belief system and teaching practices. As such, we independently selected cases and compared their systematic coherence. Because we sought to compare cases, a multiple case study design was employed to guide this research (Creswell, 2007). In this design, an issue was selected to identify the cases; then, several types of data were collected to investigate the relations in the research questions. In-service science teachers' personal epistemology was the issue that was selected for this study because the aforementioned literature suggested that epistemological beliefs are central to beliefs about learning and teaching. To identify cases, three scenarios that were developed by Kuhn et al. (2008) were distributed to in-service science teachers. These scenarios were translated into the Turkish language by the first author and another Turkish science teacher educator. A Turkish language specialist compared the translated versions to the original scenarios. Then, the in-service science teachers were ask to write their opinions on the certainty, justification of the knowledge and the judgements that were present in the scenarios. Three cases were illustrated: absolutist, multiplist and evaluativist styles. Participants were included in the study when they recorded the same label for all three scenarios. For example, an absolutist participant's responses to all the three scenarios were coded as absolutist. In general, absolutist participants defended certainty with direct observations, multiplist participants rejected certainty due to the subjective nature of human knowledge, and evaluativist participants clarified the possibility of certainty by interpreting the evidence, which was suggested by Kuhn et al. (2008).

Sample

A purposive sampling strategy was employed to select cases. The study's first author visited in-service science teachers from twelve elementary state schools (in Bolu, Turkey) to provide a brief overview of the study. Thirty in-service science teachers agreed to voluntarily participate. The three epistemic scenarios were distributed to the teachers, who were asked to respond to the open-ended questions (about the scenarios) in two days. The teachers' responses to the questions were coded according to the rubric that was developed by Kuhn et al. (2008). At the end of the coding procedure, we selected one science teacher for each category. Pseudonyms were assigned to each participant. The participants were female and had a minimum of 10 years of elementary science teaching experience in state schools. All of the participants were approximately 40 years old. Their classes contained approximately 28-30 students. Their schools had a science laboratory that was separate from their classrooms. They were allowed to conduct experiments in the classrooms if they brought the experimental materials to the classrooms. In the laboratories, there were desks that permitted the students to perform experiments with their groups.

Data Collection

Table 1 presents the timeline and data content for this study. Data collection occurred in two ways. First, we conducted audio-recorded semi-structured individual interviews. There were six interview sessions that focused on different aspects of participants' teaching belief systems. Interviews were performed on a weekly basis to preclude direct interactions among beliefs. The first interview session focused on participants' personal epistemology. The next four sessions queried participants' COTL, self-efficacy for learning and teaching science, self-construal, and PCK. The final session occurred after observing participants' teaching practices. This session included stimulated recall to understand in-service teachers' observed teaching behaviours as well as member checking. Each of the six individual interview sessions lasted for 15-20 minutes.

Data Type	Time	Data Content
1st interview	Week 1	• Interviewing about personal epistemology
2nd interview	Week 2	• Interviewing about COTL
3rd interview	Week 3	• Interviewing about self-efficacy of learning and teaching science
4th interview	Week 4	• Interviewing about self-construal
5th interview	Week 5	• Interviewing about pedagogical content knowledge
Teaching practice #1	Week 6	• Observing classroom practice
Teaching practice #2	Week 7	• Observing classroom practice
6th interview	Week 8	• Stimulated recall • Member check

Table 1: Timetable and data content

The second type of collected data was video-recorded teaching practices. Participants were provided with individual portable camcorders during their 3rd interviews and were asked to place them in the classroom to record their teaching practices. During weeks 4 and 5, the teachers placed the camcorders in the classrooms and recorded their teaching. Two weeks of video recordings were obtained to allow students and teachers to become comfortable participating in the science course that was being recorded. During these recordings, attention to the camera decreased, and video recordings from weeks 6 and 7 were obtained to represent natural teaching practices. Each video-recording included all of the participant teacher's teaching activities during a regular course period of approximately 40 minutes. Interviews and video recordings were transcribed verbatim prior to the analyses.

Data Analysis

Content analysis was utilized to analyse the data. Krippendorff (2004) stated that content analysis can be used to interpret all types of data that use language. At the beginning of the study, the coding scheme was developed based on the literature about teacher beliefs. Following Krippendorff's (2004) suggestions, the coding units were distinct categories that had two characteristics. First, they were based on the scientific literature. Second, they were suitable for the data collection method in this study. The coding units and categorical distinctions as well as samples from the interview questions are presented in Table 2. Interview questions were created by the authors after reviewing qualitative studies in the current literature. For example, phenomenological studies (e.g., Bahçivan, 2014) guided the interview questions that were related to COTL.

Interview question samples	Coding Units	Categorical Distinctions	Intercoder Reliability
What is your definition of knowledge? Does knowledge change? Why? Clarify your answer.	Personal epistemology	• Absolutist • Multiplist • Evaluativist • Sophisticated • Naïve	.92
Can you please define teaching science? What is the meaning of learning science?	Conceptions of teaching and learning science	• Constructivist • Traditional	.95
How confident do you feel while learning and teaching science? How often do you have difficulties while learning and teaching about science?	Self-efficacy of learning and teaching science	• Efficacious • Inefficacious	.95
Can you please describe yourself by ten sentences such as 'I am a……………person'? How often do you interact with other people in a day?	Self-construal	• Autonomous self • Related self • Autonomous-related self	.82
Can you please select a science topic to teach? Give examples of how you teach that topic? Do you always teach that topic with this same method? Why?	Pedagogical content knowledge	• Organization of PCK was divided into sections to represent	Not applicable
Can you please clarify which misconceptions or learning difficulties that your students have? Why did you adapt this method/approach to overcome that student learning difficulty?	Teaching practice	• Organization of teaching practice was divided into sections to represent	Not applicable

Table 2: Analysis details about coding and reliability

At the beginning of the analysis, the coding units delimited the interview questions that created boundaries for interviewee's responses. All responses were transcribed. Then, transcripts from the interviews were carefully read, and notes were recorded. Finally, based on the relevant literature, categories were created and applied to the data. At the end of the coding procedure, holistic analyses were performed to fully understand each case, and an embedded analysis was employed to investigate specific relationships in the cases. Creswell (2007) stated that holistic analyses independently focused on each case, while embedded analyses compared each case to others to understand potential relationships among the variables in the multiple case studies.

Cresswell (2007) suggests that it is important to use multiple data sources and member checking to validate the interpretations. This study used interview data in addition to participants' teaching practices. In general, the interviews reflected participant's *espoused theories of action*, while teaching practices informed the researchers about their *theories-in-use* (Kane, et al., 2002). Additionally, during the final interview, participants were asked to review certain codes. Furthermore, to examine the reproducibility (inter-coder reliability) of the results, the first author translated random parts of each coding unit from the transcripts into English. The second researcher coded these random parts based on the previously determined categories. Then, based on Krippendorff's suggestions, Krippendorff's α was calculated by hand for each coding unit (see Table 2). Krippendorff (2004) mentions that α values that are higher than .80 correspond to high reliability; therefore, the results of this study are reproducible and reliable.

Results

Holistic Analyses

Absolutistic Case

When asked about the multidimensionality of her epistemological beliefs, Burcu had naïve beliefs. She believes that '…the source of knowledge are the scientists or experts who can conduct experiments and interpret them…but if these scientists continue to discuss the results or if they are not sure, then I trust my religious beliefs.' She said that 'knowledge is generally defined as being not stable, but to me, scientific laws are certain and nobody can change them.' In addition, she believes that 'knowledge has grown since the existence of the first human, so it has many parts…a small body of these parts relate to others.' For justification, she stated that, 'knowing does not always need justification; for example, in philosophy it isn't possible to present evidence.' For domain specificity, she claimed that knowledge in physics and chemistry was more certain than in biology. 'There are still so many things to be discovered in biology.' In addition, she claimed that knowledge on the topic of electricity was more stable than knowledge in other physics topics. She said, 'I can easily show the amount of current with an ammeter when I teach, but this is not the case when I teach the concept of force. You cannot directly show it to students.'

Related to efficacy beliefs, she said, 'If I say that I feel very confident about teaching and learning science, it will not be true. But, I can teach physics and chemistry topics better than biology topics…because the borders of physics and chemistry are quite clear in comparison to biology…Especially in biology, the content is changing continuously…Students sometimes think that I am a doctor and ask so many questions. This situation gets me into scrapes.' In addition, she feels confident properly using the blackboard during teaching activities.

For self-construal, she selected descriptors that were primarily reflective of related self-construal. For example, she stated that, 'I don't like to get people upset, I cannot make people wait, I like to talk to people, I cannot argue about anything with people, and I am a compatible person.' There were only two descriptors that indicated an autonomous-self, which were that 'I don't like watching TV, and I am hasty.' However, asked about her reasons for not watching TV, she said, '… I prefer talk to somebody at home.' When asked how these descriptors affected her teaching, she mentioned, 'I have good relationships with my students. I do not get angry with them…To prevent them from stressful discussions, I do not utilize arguments in my teaching…Sometimes, I teach for less time than the regular classroom hour because I, unfortunately, am hasty.'

Finally, she defined learning science as, 'getting the cumulative body of knowledge as a requirement for living. People who have scientific knowledge feel confident in their lives and are aware of everything around them.' Her definition of teaching science was, 'making students enjoy science courses.' To achieve this goal, 'a science teacher should continuously employ different activities, such as conducting experiments, writing on the blackboard, and clarifying necessary points.'

PCK and Practice

When asked to present an example of how she teaches a specific topic, she was not able to identify a specific example in the moment. She preferred to make domain-based comparisons. For example, she said, ‘especially in biology topics, I try to perform experiments to prevent my students from continuously writing.’ She mentioned that there were many writing requirements for students in biology topics. In contrast, in physics topics, she preferred to directly explain the concepts for two reasons. To her, the physics topics had several mathematical formulae, and the students had many misconceptions about physics concepts. She said, ‘the mathematical aspect of physics overthrows them, but using demonstrations and making clarifications positively contribute to their understanding and permanence of physics knowledge.’ Table 3 represents her lecturing as organized through PCK.

In her video recorded course periods, she began the lectures by selecting a student to read a question from the textbook, which queried students’ ideas about whether pieces of a broken glass were still glass. She continuously provided additional examples and asked questions that required students to respond with yes, no, right or wrong. When students could not differentiate between physical and chemical change at certain times (see Table 3), she asked a new question, such as, ‘do you think that a broken egg transforms into new matter?’ ‘Transforming into new matter’ reflected the overall goal of her lecture. During following examples, some students still struggled to comprehend this idea. She asked the same question again in these situations. Some other students responded with a yes or no. Very few students already knew the concepts that were reviewed in the lectures. She said, ‘these students take additional courses from private course centres to proceed faster than their friends.’ She sometimes warned these students that there were other students in the classroom. Throughout most of the course, she used the blackboard to record certain examples and student answers. Each time that she recorded a note on the blackboard, she directly clarified whether there was a transformation. At the end of the second lecture, she performed a basic demonstration that was presented in the textbook. The demonstration was to make changes to everyday materials. After each change activity, she asked, ‘which type of change occurred right now?’ During the stimulated recall interview, she mentioned, ‘this type of questioning positively contributes to permanence in the student’s understanding.’ She said that she did not know of any misconceptions but that there were learning difficulties in this topic. She believed that by questioning and using the textbook, she provided most students with an understanding of the transformation of matter.

PCK for Teaching of Chemical and Physical Change
Subject matter knowledge
Chemical change is not reversible and causes a substance to transform into a different substance. Physical change does not change characteristics of substances.
Aims/purposes
Understand differences between physical and chemical change
Student characteristics
Most of the 6^{th} grade students did not have preconceptions directly about chemical and physical change. Students could not differentiate chemical and physical change at certain examples such as breaking an egg, biting an apple, making ayran with yogurt.
Teaching Representations
Questioning for taking examples from the students Direct instruction for meaning making Demonstration of certain changes at classroom
Teaching Materials
Textbook was used as the framework for the lectures Blackboard was used to write certain student examples and answers Everyday materials (such as pecan, chick pea, sugar and spirit lamp) were utilized to make the demonstration in the textbook.

Table 3: Practice based PCK organization of absolutist case

Multiplistic Case
Beliefs

Ayşegül, the multiplist participant, believed that knowledge is rarely certain. She said, ‘in most cases, knowledge is changing, especially in science, such as astronomy, so you cannot say that it is certain.’ She stated, ‘sources of knowledge are scientists and specialists…I know and am aware of many things around me, but that is my knowledge…I am not the source of knowledge.’ For simplicity, she believed that knowledge had thousands of bits that were connected to each other. This network made knowledge complex to understand and was also responsible for subjectivity. She stated ‘justification is needed to make confirmations…Everybody can make their own verifications in different ways, I mean you can reach only to your truth.’ For domain specificity, she claimed that knowledge had different characteristics that were aligned with domains. She said, ‘according to me, chemistry, in the near future, will encounter more change than other domains because in physics and biology you can see most of the things that you are trying to understand. However, an atom is a thing that we cannot directly see, so most scientists will use new models to visualize it.’

For self-efficacy beliefs, she stated, ‘I do not have problems with learning, I see myself as successful in this aspect.’ She also felt confident about teaching. She said that ‘even when I sometimes have difficulties teaching abstract concepts, I use different representations, such as illustrations, experiments and visual materials.’ When she was asked to provide more specific examples, she said, ‘when I give a lecture about the concept of force in physics or elements in chemistry, I feel more confident because these topics are not related to other topics, and students can more easily comprehend these concepts.

She described herself as hasty, tidy and compassionate. She also said, ‘I use body language, I don’t like to argue, I am affected by individuals in my environment, I care for others, and I am a social person.’ Her descriptors primarily indicate a related self, and she confirmed this in the last sentence. Thus, she has a related self-construal. When asked how these characteristics affect her teaching, she stated, ‘I feel how my students feel themselves, I have strong relations with them…I ask them to complete their homework on time’.

She defined learning science as a process of recognizing, meaning making, and constructing an individual awareness. She said, ‘I still learn from my students’ unexpected questions that allow me to make connections among different concepts.’ She defined teaching science as supporting students’ meaning making processes as a subject matter specialist. When asked why she thought teachers should be subject matter specialists, she responded in two ways. First, she indicated that subject matter knowledge allowed her to identify students’ learning issues. Second, it allows her to adapt appropriate teaching strategies.

PCK and Practice

Ayşegül provided a PCK example from her current lectures. She had taught buoyancy in the classroom in which we interviewed. She mentioned that this topic included many different concepts (such as volume, force, weight and density) that students had to connect. To her, this situation reflected general student learning difficulties in buoyancy. As such, she said, ‘I first introduce these concepts separately and then conduct collaborative classroom experiments to provide them with comprehension of the relations among these concepts. There are different types of experiments that are possible …Considering their difficulties, I adapt appropriate ones…However, in some classrooms there are a large number of students, which prevents successful inquiry.’ Table 4 presents her actual teaching practices as organized with PCK.

In her video recordings, she began the lecture by explaining the name of the topic and reminding students of previously learned points about the concept of force. Then, she directly asked whether they knew anything about pressure. Students often had similar definitions, although several stated that pressure was a force that was applied on the ground. She did not address this definition. After a while, she presented the daily materials (see Table 4) on her table and asked some questions. For example, she asked, ‘which side of the nail should be stroked with the hammer and why?’ During similar questions, she gave reinforcement to the students who have the correct answers, but did not acknowledge the wrong answers. In the second lecture, she distributed balloons and a nail to students and asked them to pop the balloons with both sides of the nail. She observed and asked which side of the nail popped the balloon. Similar to when she asked the previous questions, some students provided wrong answers, which she did not acknowledge. Then, she wrote some bullet points on the blackboard as reminders of the exercise and asked students to interpret the relationship between pressure and surface. At the end of the second lecture, she asked students to provide daily examples about pressure. During stimulated recall, she stated, ‘I prefer to use everyday materials and questions to teach about pressure. In this way, in my experience, they are more motivated than with direct instruction.’ When interviewer reminded her about students’ incorrect answers that ignored the difference between magnitude of force and force, she said that she had not realized this misconception.

PCK for Teaching of Pressure
Subject matter knowledge
Pressure is the magnitude of force for per unit of surface. There is reverse relationship between magnitude of surface and pressure.
Aims/purposes
Understand the relationship between pressure and surface Give examples from daily life related to pressure
Student characteristics
8th grade students did not have preconceptions directly about pressure. Students think that pressure is a type of force
Teaching Representations
Questioning for taking examples from the students Direct instruction for meaning making Illustration of relationships with everyday materials
Teaching Materials
Blackboard was used to write bullet points. Everyday materials (such as hummer, nails, wooden platform, screws, and balloons) were utilized in illustrations.

Table 4: Practice based PCK organization of multiplist case

Evaluativist Case
Belief

Sergül believes that knowledge is not certain. ‘Every type of knowledge changes… Science and technology affect each other, new things continuously appear, and our thinking should be adapted to a new interactional body of knowledge.’ To her, the source of knowledge is thinking, evidence and communication. Knowledge has related parts, and these relations open the door to new ideas. She claimed that justification was required to decide the validity of all knowledge. She said, ‘even in contradictive situations, I look for the evidence and make comparisons to arrive at a decision.’ For domain specificity, she said that knowledge in all domains changes, but ‘biology changes more rapidly in comparison to other domains…By adapting developments in quantum physics, biologists have been discovering new evidence about the structure of microorganisms.’

She is an efficacious teacher in terms of learning and teaching science. She said, ‘learning and teaching are lifelong processes, but I believe I can succeed in them because I am an experienced teacher…my students, their parents and sometimes my colleagues give me positive feedback, especially for my teaching’.

She defined herself as a mother and an emotional, patient and thoughtful individual, which are characteristics the primarily correspond to related self-construal. She also said that she was a rational person, a thinker, an observer, and that she liked to read. These characteristics correspond to an autonomous self-construal because they are personal characteristics. Therefore, Sergül has an autonomous-related self-construal. She mentioned that her characteristics allowed her to use brainstorming as a learning strategy in her teaching activities.

To her, learning science is, ‘perceiving and constructing awareness. This mostly occurs individually because the people who learn science are actually the ones who learn how to learn.’ She believes that these people are also sceptical and look for evidence and interpretations in their daily lives. She defined teaching science as a process of supporting different types of thinking and creating such thinking environments.

***PCK and* Practice**

Sergül discussed a specific PCK example about resistance in electricity during the interview. She said, 'I first try to explain what a lamp is. I construct a simple circuit and ask questions, such as what is happening now, why is the lamp giving light, and what does it need to give light?' From her perspective, students did not understand resistance in electricity circuits. Then, she said, 'I clarify the definition of resistance and its mathematical calculations.' Table 5 presents her practiced PCK organization.

At the beginning of the video recorded lectures, she warned students to be ready to learn a new concept. She drew six boxes on the blackboard, each of which represented the concepts of force, newton, effect of force, type of force, dynamometer, and elastic substance. She investigated students' preconceptions about these concepts with simple questions. Then, she requested volunteer students to apply force to the chair in the front of the classroom (see Table 5). Students tried to apply force for different purposes. Each time, she asked what students did and how they did it. At the end of the first lesson, she requested that the students form groups of two students. She distributed plastic balls to each group and asked them to prepare a paper for the next week's lecture to explain what they could do to the plastic ball by exerting force and how they could measure the weight of the balls. In the next lesson, she collected the group papers and repeated the questions. Students provided similar answers; then, she started a powerpoint slide presentation about dynamometers and units of force. She distributed dynamometers to students to measure the weight of plastic balls. At the end of the lecture, she summarized all the concepts and wrote bullet points on the blackboard. During the stimulated recall, when asked whether she addressed student misconceptions, she said, 'I actually consider their misconceptions, but this time I did not encounter any. They mostly have difficulties measuring the weight with a balance rather than a dynamometer.'

PCK for Teaching of Force Concept
Subject matter knowledge
Force is applied on matters to change their shapes and movements. Force has a direction. Force is measured with dynamometer and Newton is accepted as the unit of its magnitude.
Aims/purposes
Understand basic principles about force.
Student characteristics
5th grade students are being firstly introduced with this concept, so they have no direct preconceptions.
Teaching Representations
Direct instruction for entrance and introducing of certain concepts Guided inquiry was adapted partially Illustration of certain effects of force at classroom
Teaching Materials
Blackboard was used to introduce concepts. PowerPoint Representation Everyday materials (such as plastic balls and chair) and dynamometers were utilized in illustrations.

Table 5: Practice based PCK organization of evalualitivist case

Embedded Analysis

To perform the embedded analysis, all of the categorical distinctions from the holistic analyses are presented in Table 6. In the embedded analyses, the inter-relational pathways among the codes were examined. In summary, when science teachers present characteristics of autonomous self-construal more than related self-construal, they have a more advanced personal epistemology. Science teachers' personal epistemology (that were attained according to the developmental tradition) also predicts epistemological sophistication for multidimensionality. That is, when science teachers have more advanced epistemological views, they also have more sophisticated epistemological beliefs on all dimensions. This epistemological sophistication, combined with their autonomous self-construal characteristics, forms their COTL. Qualified beliefs trigger constructivist conceptions. Moreover, qualifying these teaching beliefs positively relates to self-efficacy beliefs for learning and teaching science. Finally, a more powerful belief system allows for a more qualitative PCK, which is evidenced through their teaching practices.

Discussion

This study selected participants based on their epistemological perspectives because epistemological beliefs have an effect on science teachers' beliefs about teaching and learning (e.g., Chan & Elliott, 2004; Hofer & Pintrich, 1997). In this respect, our discussion first focuses on the results related to the participant teachers' personal epistemology. We applied Kuhn et al.'s (2008) coding scheme to the participants' responses for the epistemological scenarios. After identifying the cases, individual interviews were conducted to determine whether their epistemological beliefs had multidimensionality and domain specificity. The results are partially consistent with Schommer-Aikins (2004) because the science teachers' epistemological beliefs differed in accord with their epistemological dimensions (such as certainty, simplicity, source, and justification). The participants were aware of these different dimensions and had specific epistemological beliefs for each dimension. However, their developmental coding labels already predicted their epistemological beliefs. That is, when the participant had an absolutist perspective, she also held naïve epistemological beliefs.

Personal Epistemology[*]		Self-Construal	COTL	Self-efficacy[**]	PCK and Teaching Practice
Absolutist	C. Naïve Si. Naïve S. Naïve J. Naïve	Related	Traditional	L. Inefficacious T. Inefficacious	Questioning, Direct Instruction, Demonstration Learning difficulties were unconsidered
Multiplist	C. Sophisticated Si. Sophisticated S. Naïve J. Sophisticated	Related	Constructivist	L. Efficacious T. Efficacious	Questioning, Direct Instruction, Illustration Misconceptions were unconsidered
Evaluativist	C. Sophisticated Si. Sophisticated S. Sophisticated J. Sophisticated	Autonomous-related	Constructivist	L. Efficacious T. Efficacious	Guided inquiry, Direct Instruction, Illustration Misconceptions were not realized

[*]C. is certainty, Si. is simplicity, S. is source, J. is justification.
[**]L. is efficacy of learning science, T. is efficacy of teaching science.

Table 6: Holistic analyses results presenting the coding results

For domain specificity, the results did not support this tradition. At first appearance, the quotes from the participants appear to provide domain specificity, but we detected that this was not the case. The domain based differentiations actually corresponded to participants' experiences and knowledge about the domains. When the participant had bad experiences with or more extensive knowledge in a domain of science, differences in her epistemological beliefs were based on these experiences. This result is consistent with Muis et al.'s (2016) findings. As such, we conclude that the developmental tradition in personal epistemology may have a more valid framework than multidimensionality and domain specificity for clarifying elementary science teachers' personal epistemology.

Furthermore, during the embedded analysis we found that qualifications in personal epistemology positively affected in-service science teachers' COTL and self-efficacy for learning and teaching. This is consistent with research by Hofer and Pintrich (1997) and Brownlee et al. (2002) as well as the empirical evidence that Chan and Elliott (2004) presented. However, the relationship among these beliefs did not guarantee teachers' qualification in their PCK and practice. For example, even though our multiplist case had sophisticated epistemological and constructivist beliefs and felt self-efficacious in teaching science, her PCK and practice frequently included direct instruction. This reverse relationship was already found in comprehensive literature reviews on teaching beliefs (e.g., Fang, 1996; Kane et al., 2002).

At the beginning of the study, we attempted to investigate a more comprehensive teaching belief system to understand consistencies among science teaching belief systems, PCK and practice. Self-construal was selected because it has cultural substance (Kağıtçıbaşı, 2007) and centrality in a teaching belief system (Rokeach, 1968). Indeed, the evaluativist case demonstrated an increase in the number of autonomous self-construal characteristics (such as thinker and observer). These characteristics appeared to directly penetrate her justification and positive reasoning. In that case, there was a more coherent science teaching belief system between her PCK and practice compared to the multiplist case. To activate epistemological sophistication, autonomy in self-construal seems to be necessary. Our multiplist case also had sophisticated epistemological beliefs; however, these beliefs did not affect her PCK and teaching practices. In addition, in the evaluativist case, the participant claimed that her autonomous characteristics allowed her to integrate brainstorming and arguments into the teaching activities. In contrast, the absolutist and multiplist teachers could only claim that their characteristics supported their communication with their students. As such, the findings partially support the idea that science teachers' beliefs about themselves are more central than the epistemological beliefs in their science teaching belief systems.

To address our first research question, we conducted a series of interviews to investigate coherence among the in-service science teachers' teaching beliefs. The results showed that there were interactions among participants' self-construal, epistemological beliefs, COTL, and self-efficacy beliefs, such that these interactions corresponded to a part of a science teaching belief system. This science teaching belief system had a hierarchy among beliefs, which was proposed and evidenced by Rokeach (1968). Of these, self-construal corresponds to Types A or B as they reflect beliefs about the self. Epistemological beliefs correspond to Type C (also called authority) beliefs, as they determine people's views of direct knowledge. COTL correspond to Type D beliefs because they were derived from epistemological beliefs. Finally, through the embedded analysis, we found (see Table 6) that qualification in all of these beliefs combined with participants' enactive attainments and verbal persuasions positively affected the in-service science teachers' self-efficacy beliefs. As such, we conclude that their self-efficacy beliefs are derived from other teaching beliefs; thus, they are the most peripheral (Type E) of all the beliefs.

Before discussing our results from the second research question, we believe it is important to clarify the observations about the participants' PCK and science teaching practices. In addition to interviews, we recorded participants' classroom practices to obtain a more comprehensive view of their PCK (Baxter & Lederman, 1999). During the interviews, we realized that it was very difficult for the participants to create examples of their PCK. As such, we believe that science teachers' PCK and actual teaching practices cannot be separated. Their actual practices represented a cross-section of their actual PCK. The PCK organizational framework that was developed by Hashweh (2015) expedited a portrayal of their core PCK, which involved knowledge of learners and knowledge of representations (Lee & Luft, 2008).

For the second research question, our results supported research that found coherence between science teachers' teaching belief systems, PCK and teaching practices (Pajares, 1992). As discussed above, including self-construal in the science teaching belief system empowered coherence in science teaching beliefs. If we had not matched self-construal to the teaching belief system, we would not be able to explain why the multiplist science teacher did not behave as the evaluativist teacher in her classroom teaching practice. However, we have partial evidence that science teachers' epistemological beliefs may be triggered by their self-construal. This belief system appears to have a hierarchical order that is dominated by self-construal. This domination was clearly detected in participants' PCK and teaching practices. Although the evaluativist and multiplist cases had similar epistemological beliefs, only the evaluativist case had a qualified PCK in her teaching practice. Our results showed that this discrepancy might be caused by the evaluativist teacher's self-construal, which included autonomous characteristics.

Conclusion

For the first research question, we conclude that science teachers' beliefs may have a hierarchy based on the embedded analysis results. In other words, the elementary science teachers' teaching beliefs combined with their self-construal may be causal relationships that begin with central and connect to peripheral beliefs, which may construct a belief system. For the second research question, we conclude science teachers' beliefs were not independently coherent with their PCK and practices. These beliefs appeared to interact with each other in a system. The coherence among all of the beliefs had a systematic coherence with their PCK and practices, which is clearly supported in Rokeach (1968) and Fishbein and Ajzen's (1975) research.

Limitations and Implications

We selected a group of science teaching beliefs based on evidence from the literature on science teacher education and psychology. However, there was much more information than we could include in this study. Including more comprehensive beliefs may influence the results. Additionally, we had only 3 participants and believe that examining a larger number of science teachers may allow us to observe different relations among the selected beliefs, PCK and teaching practices. Finally, the duration of data collection is another limitation. The participants' classrooms were observed for two weeks. Longer observation periods may change the relations that we detected among the variables.

Given the above limitations, we call for additional research to investigate these relations with more comprehensive belief systems and/or a higher number of participants to contribute to the external validity of our interpretations. Importantly, we suggest that it may be helpful to integrate 'self-education' into science teacher education programmes after additional research confirms the results of this study. The findings about self-construal demonstrate that it may have an effect on science teaching beliefs. Science teachers' autonomous characteristics appeared to empower their tendencies towards sophisticated epistemological beliefs and constructivist learning practices. We can develop such courses to support pre-service science teachers' autonomous characteristics. Similarly, professional development programmes for in-service science teachers could include similar courses or workshops. Beliefs about the self are very difficult to change because they are the most central beliefs (Rokeach, 1968). However, we may collaborate with social psychologists to develop such courses or workshops.

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